

# White Paper Report

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Final Report  
PF-50169-11

**Planning: Upgrading Climate Control to Preserve Audiovisual Collections**

**Environmental Conditions for Archival Sound Recordings**

Project Director: Michael A. Keller

Stanford University  
February 2013

**White Papers**

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## **Planning: Upgrading Climate Control to Preserve Audiovisual Collections**

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Image Permanence Institute  
Herzog/Wheeler & Associates, LLP

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## PROJECT OVERVIEW

As part of a 2011-2012 National Endowment for the Humanities Sustaining Cultural Heritage Collections Planning Grant, the Stanford University Archives of Recorded Sound (ARS) contracted with the Image Permanence Institute (IPI) and Herzog/Wheeler & Associates, LLP, to conduct a year-long study of mechanical system optimization and environmental data analysis related to one mechanical system in the Braun Music Center and the associated collections storage spaces that it serves. The goal of the consultancy was to gather information and data that would enable the Stanford Music Library and ARS staff to make informed, strategic decisions regarding long-term collection stewardship, mechanical system operation, and sustainable practices. The IPI consultant for this project was Jeremy Linden, Preservation Environment Specialist at IPI.

As part of the grant, ARS purchased PEM2® dataloggers for installation and datalogging in the mechanical systems and collections spaces, as well as the consulting services. In addition, IPI installed one ACR TRH-1000 datalogger at their expense to log conditions after the cooling coil of the unit. Data gathered during the project was initially uploaded to IPI's PEMdata website, and later transferred to the new EClimateNotebook™ web analysis platform, where it was available to all participants. ARS provided access to the expertise of a team of Stanford staff, including representatives from ARS and the University Library, Buildings and Ground Maintenance, and the Department of Sustainability and Energy Management. IPI made two trips to work with Stanford staff onsite in November 2011 and May 2012.

This report represents the final deliverable from IPI and Herzog/Wheeler to the Stanford University Archive of Recorded Sound in fulfillment of the consulting agreement. The system studied is examined and documented in detail as to the system layout, as found operation and energy implications, and preservation implications of the as found conditions. Lastly, final recommendations for collections preservation and optimized operation are given for the current system parameters. In addition, recommendations to consider for future capital improvements to system and space design, based both on preservation needs and energy optimization, are covered in the final section.

Jeremy Linden  
Image Permanence Institute  
October 2012



## OVERVIEW SUMMARY

This report contains two sets of recommendations, one for improved preservation and efficiency at AHU #2 without any capital improvements, and one for design considerations for a new system and the space if capital improvements are made. Details regarding these recommendations are included in the report.

### **Operational recommendations:**

To improve preservation in ARS with adjusted operation at AHU #2:

- Work to achieve a consistent 51°F dew point from AHU #2 during dehumidification season (April through October) by ensuring that the cooling coil valve is 100% open when mixed air dew points are higher than 51°F, possibly reducing the minimum amount of outside air, and adding a dew point control component to the economizer control to only bring in additional outside air when the temperature set point is met and the outside air dew point is less than 51°F;
- This approach will only result in an approximately 20% improvement in the preservation environment, and still will not improve conditions to an acceptable level for the rate of chemical degradation;
- This approach will also likely result in a significant increase in energy usage at both the cooling coil in AHU #2 as well as at the downstream reheats.

The best-case scenario for optimization at AHU #2 to maintain the current quality of the preservation environment and reduce energy expenditure, without capital improvements includes:

- Improving subcool/reheat control to ensure that the subcooling is only performed when the dew point of the incoming mixed air is higher than 57°F (this strategy could also be applied with the above preservation improvement, with an incoming dew point above 51°F, with less impact)
- Experimenting with expanding the nightly shutdowns by one to two hours to further reduce energy usage; and
- Confirming and correcting unnecessary cooling behavior at the cooling coil and economizer during the "winter" months (November through March).

### **Recommendations for Capital Improvements:**

Recommendation 1: Physically separate ARS storage from the rest of AHU #2's zone by installing an insulated wall between the current ARS storage areas and the ARS reading room.

Recommendation 2: Reconfigure ARS storage as unoccupied space by moving current workstations into the ARS reading room/office area. The goal should be for the ARS storage to only be occupied when retrieving or shelving materials.

Recommendation 3: Install a new AHU to serve only the ARS storage area, with humidification, design capability of maintaining a 45°F summer dew point, and using minimal outside air. Design temperature set point should be 60°F (with operation up to 62°F). Maximum summer RH should be no higher than 55%, with minimum RH at 35% during drier periods. Additional details can be found on pages 29-31 of the report.

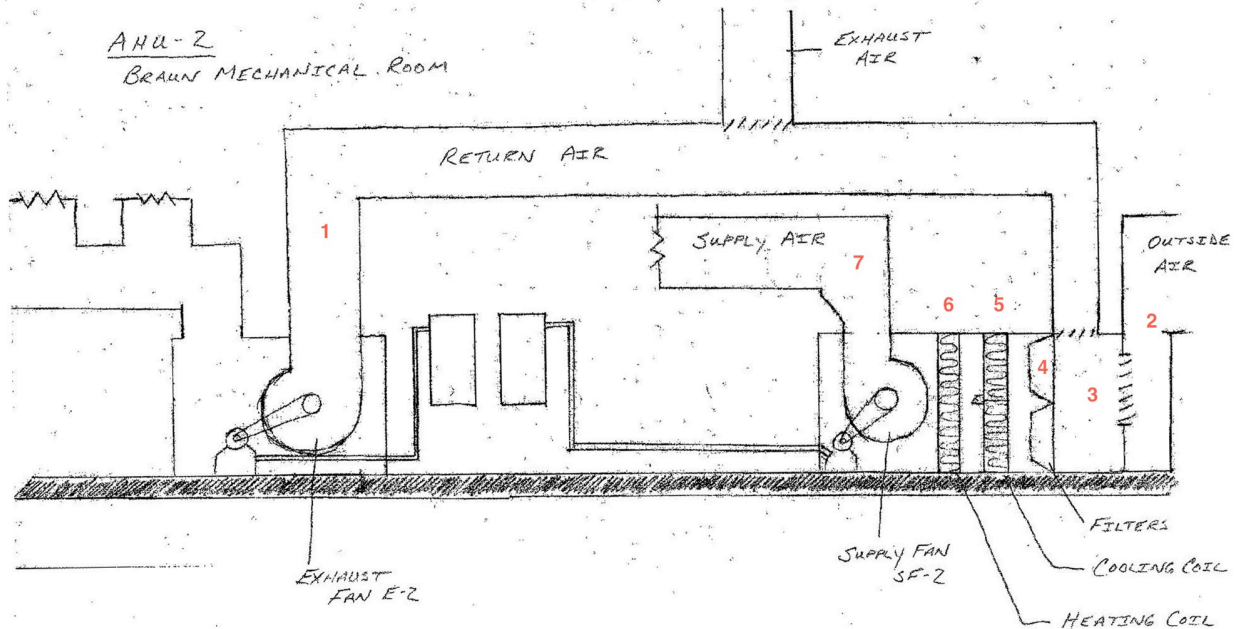
## AHU #2: ARS, MUSIC LIBRARY, AND 2ND FLOOR



### System Notes:

- Location: Mechanical Room, Ground Floor
- Layout: Subcool and reheat, no humidification. Terminal equipment is variable-air-volume (VAV) boxes with dampers and reheat, controlled by local thermostat.
- VFD: Yes, on both return fan and supply fan.
- Zone Served: Zone covers entire basement (including ARS), as well as the 1st floor Music Library area, and 2nd floor practice rooms and lounge
- Outside Air: Designed for 8% outside air, variable to 100%. Taken in from adjacent exterior of building. Current minimum set to 30% for occupation.
- Economizer: Run on temperature control only, set to provide 61-65°F supply air temperature
- Access Panels: Right side of unit as viewed from mechanical room entrance.
- Dataloggers:
  - 5 in unit – outside air, return air, mixed air, cooled air, and supply air
  - 2 downstream – supply air from VAV B-8 and B-8A
  - 3 in space - ARS east, ARS west, and ARS Reading Room
- Controls: Emerson Controls

## AHU #2 System Cartoon:



The previous diagram lays out the arrangement of the unit looking from the right (south) side. The airflow of the system is as follows (clockwise):

1. Return Air from space, driven by exhaust fan E-2
2. Outside Air from adjacent exterior of building
3. Blends with Outside Air in the mixed-air chamber, before filtration. The return air and outside air dampers control the percentage of outside air that is being used during economy cycles
4. Filters
5. Cooling Coil - 100% of air passes over the coil
6. Heat/Reheat Coil - 100% of air passes over the coil
7. Supply air to downstream VAVs. The VAVs (not shown) determine the final condition of the supply air to the space.

## Design specifications:

- Total Airflow: 21,750 CFM
- Airflow over coils: 21,750 CFM
- Outside Air (design): 1,750 CFM (calculated, equals 8% of total air through unit)
- Cooling Coil Leaving Air Dew point: 52°F
  - (based on design face dry-bulb and wet-bulb temps)
- The design cooling capacity assumes entering chilled water temperature of 46°F.

### **As Found Operation Notes:**

- Outside Air (as found): 30% minimum (calculated, equals 6,525 CFM from outside air)
- Entering chilled water temperature at cooling coils (from central plant): 43°F

### **Zone:**

AHU #2 serves the basement and portions of the first and second floors of the Braun Music Center. The area of primary concern for preservation is the Archive of Recorded Sound (ARS), located in the south and west portions of the basement level. This area is almost entirely subgrade, bounded by earth below the floor, the north and south walls, and portions of the west wall. The east wall is shared by music library stacks on one portion, and by the mechanical room on the other.

ARS is divided into two main areas, a reading room and the main storage area, separated by a cage wall. Two smaller spaces, an office and an audio listening room, are directly off of the reading room space. There is one main supply duct which supplies both ARS areas as well as a portion of the of basement music stacks. This supply duct feeds into five total VAV boxes in the ARS, one for the reading room, one for the office, one for the listening room, two in the storage area. These VAV boxes allow for some degree of local control in spaces. Return is through a common space above the drop ceiling in the Reading Room.

Collections storage in ARS has been undergoing a transition over the past several years as some materials have been moved to offsite storage at Stanford Auxiliary Library (SAL) 3. The majority of the materials that will remain onsite consist of vinyl and shellac grooved discs, with small amounts of CDs, Laserdiscs, and 8-tracks. Other audio formats – reel-to-reel, glass and lacquer discs, and cylinders – have either already been moved to SAL3 or are in the planning process to be transferred. In addition, archival collections of publisher's catalogs and sheet music, with disc jackets adding another dimension of concern for preservation, will remain onsite at ARS.

The Reading Room and ARS storage areas are both currently occupied spaces, with one primary workstation in the storage area, and free air exchange between the storage and reading room areas. There are potential sources of heat gain to the system through equipment and lights, and a source of moisture gain through a small custodial closet in the storage area.





Approximate location of ARS on ground floor of Braun Music Center.

### **Preservation Requirements:**

Based on material types stored within the zone, goals for the preservation environment should be a consistently cool temperature with year-round relative humidity ranging between 35-55%. Primary risks for a space with these types of materials include a high rate of chemical degradation due to higher temperatures and high relative humidity, physical damage to sensitive materials such as plastics and adhesive on paper caused by seasonal patterns of high and low relative humidity, and mold growth due to high relative humidity. Maintaining an appropriate indoor environment requires three primary capabilities from the mechanical system: the ability to adequately dehumidify in summer, the ability to humidify in winter, and the ability to cool to desired temperatures year round.

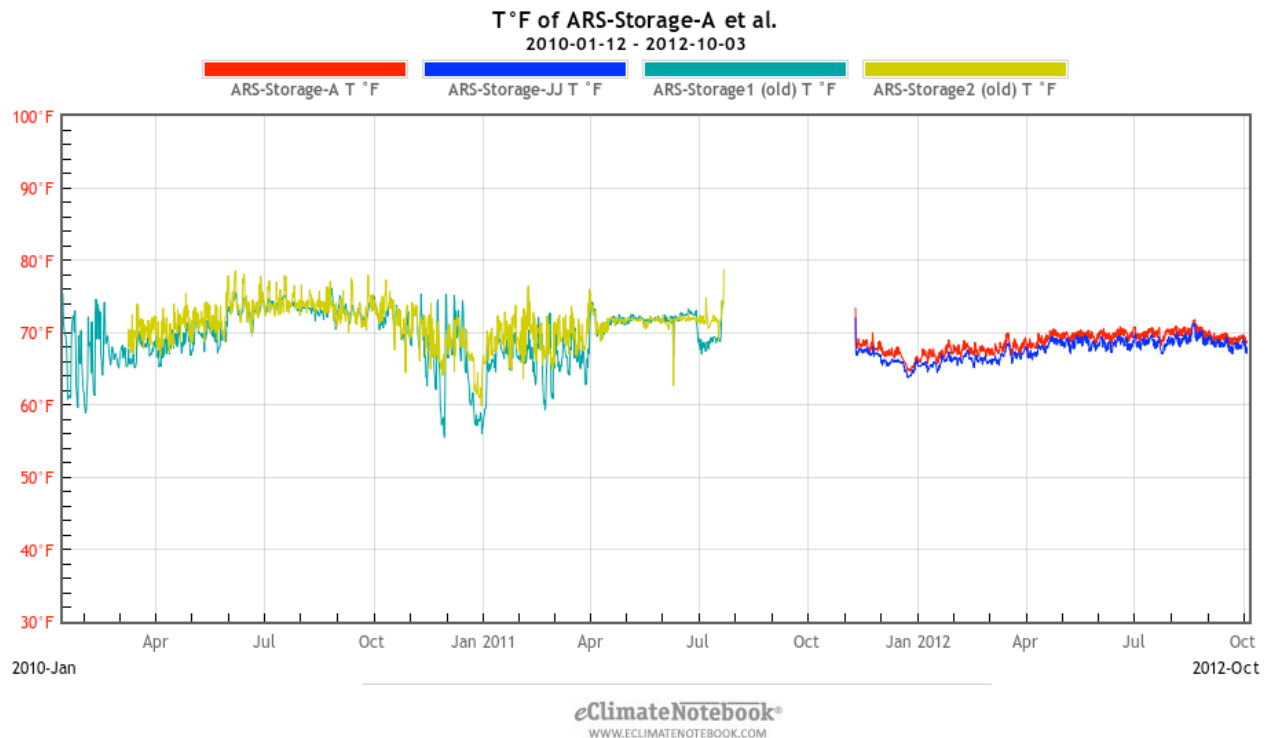
### **Zone Datalogging:**

The ARS was monitored by three PEM2 dataloggers – one in the east end of the storage area in compact shelving (located in Aisle A), one in the west of the storage area on open shelving (located in Aisle JJ), and one on the open reference shelving located in the reading room area. In addition, historic temperature and relative humidity data was available from three sources - two PEM2s that were kept in the space from roughly January 2010 to August 2011, and one PEM1 that is still logging in the space.

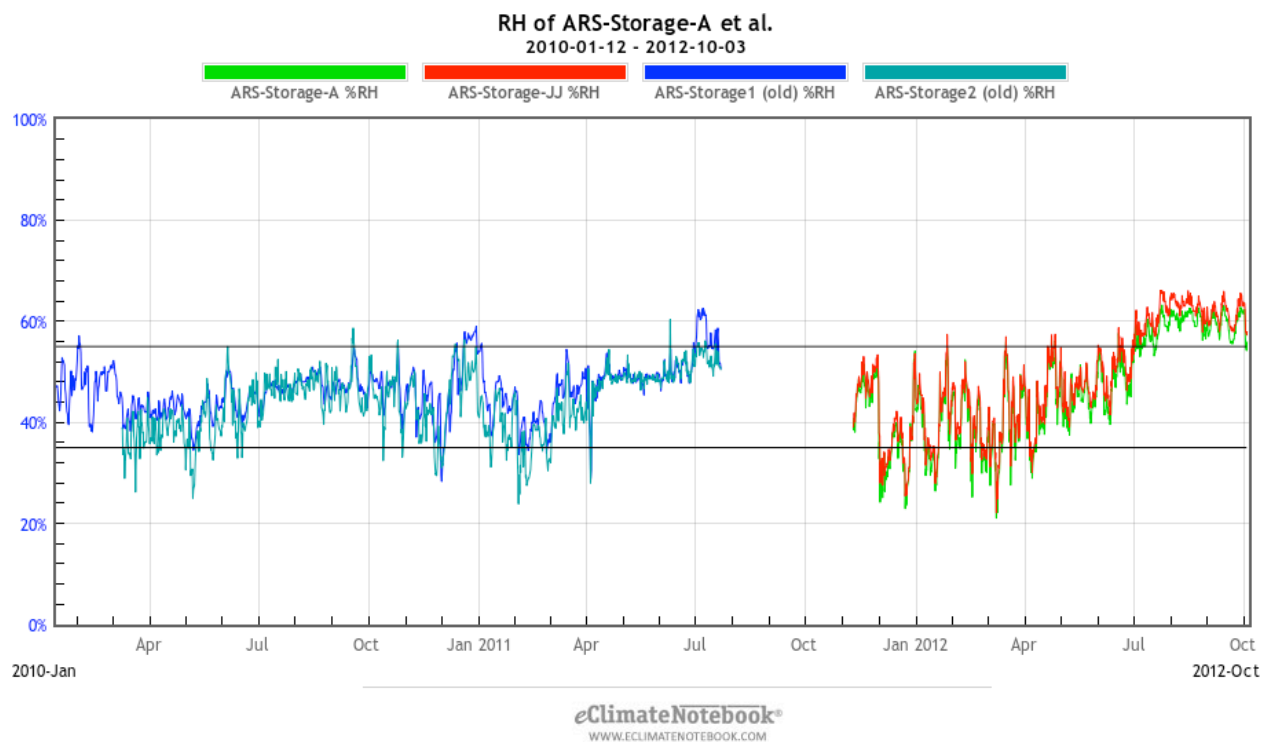
### **Measured ARS Storage Environmental Conditions:**

ARS began logging in the storage area in January of 2010. Since that time, temperatures in the space have ranged between 60 and 75 deg. F (with occasional excursions higher or

lower), with seasonal variation - summers trending warmer and winters trending cooler. RH conditions fluctuate widely, peaking near 70% in the summer of 2012, and dropping to below 20% in the winter of 2011/2012. Summer dew points in the space have historically ranged between 52°F and 58°F.

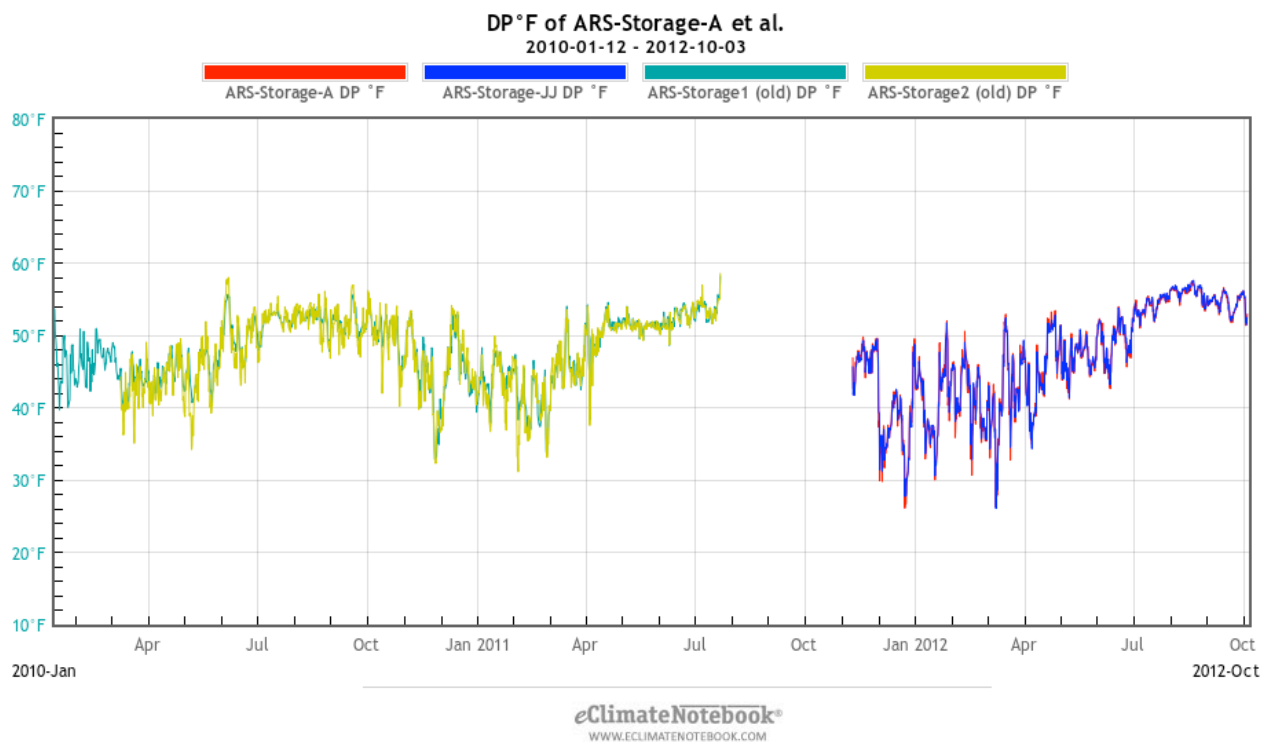


The above space temperature graph shows two periods of data from the ARS storage area - that gathered during the period between January 2010 and August 2011, and that gathered during the course of this project, from November 2011 to early October 2012. One thermostat controls the two VAV boxes (B-8 and B-8A) that serve the ARS storage area. These two VAV boxes control the volume of cool supply air from AHU #2 to modulate temperature. They can also heat the supply air from AHU-2 in order to determine the ARS storage space temperature at any given time. Historically, there is a noticeable seasonal temperature variation in 2010-2011 that is dampened during late 2011 to 2012. The current documented temperature - ranging between 65°F and 71°F - illustrates the need to maintain human comfort conditions within the space, as well as the potential difficulty of maintaining cooler temperatures given the open exposure to the human-occupied reading room area.



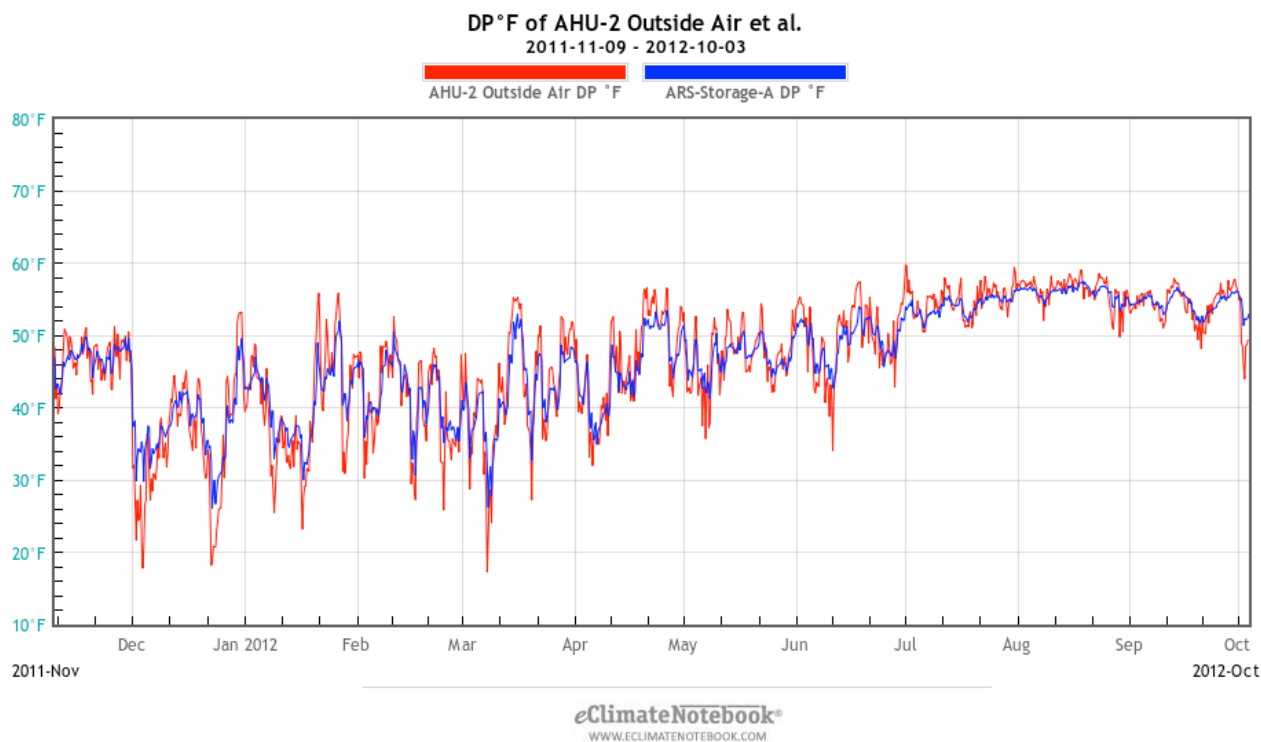
As above, the pictured RH graph (limit lines at 35% and 55%) shows both the historical data gathered by ARS prior to this project, as well as that gathered over the past year. The higher RH's in the summer of 2012, compared to those seen in the summer of 2010, are attributable to a combination of slightly higher dew point (shown below) and consistently lower temperatures. The low RH's in the winters of 2010-2011 and particularly in 2011-2012 are primarily due to the lack of any humidifying capability on the system. Without humidification, RH levels will fluctuate and drop based on the dew point (primarily created by the dew point of outside air being brought into the system) and temperature.





The high dew point temperatures in the summers of 2010, 2011, and 2012 are typically higher than the 52°F design dew point temperature that the cooling coil is capable of. Because the central plant actually supplies chilled water at a lower temperature than the coil was designed for - the coil was designed for 46°F water, while the plant typically supplies 43°F water - it is likely that the coil is not operating to its full capacity.

Comparing the indoor dew points to the outdoor dew points provides some insight into moisture in the preservation environment compared to outdoor moisture content. The graph below shows the space dew point (blue plot) with the outdoor air dew point (blue plot) overlaid. Indoor dew points fluctuate widely and tend to track very closely with the outside dew point conditions, indicative not only of the lack of humidification in winter, but also of the fact that the system may not currently dehumidify up to its full capability in summer. The moisture buffering effect of the building envelope, and the fact that outside air is typically only a portion of the air circulated through the space, explain the fact that indoor dew point never fluctuates to the full extent of the outdoor dew point.



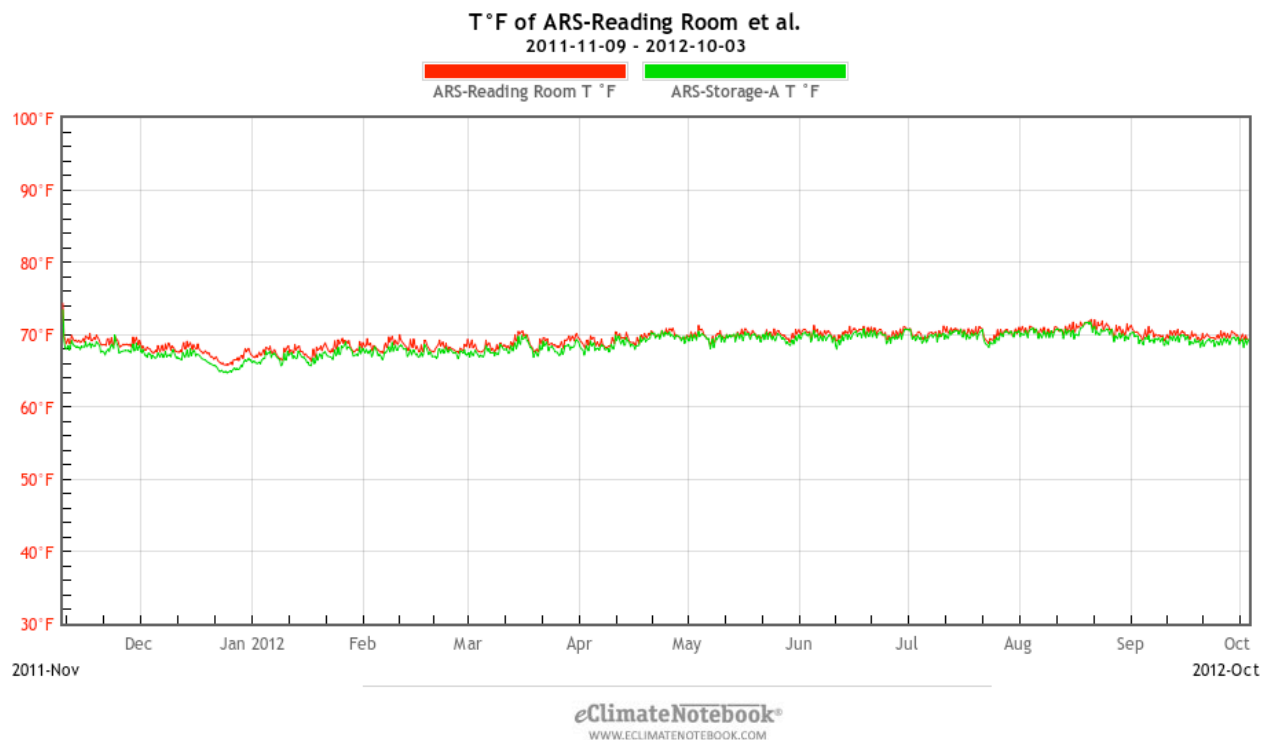
Moisture control is the most critical aspect of maintaining an appropriate preservation environment. Adequate dehumidification during damper summer months allows for maintenance of appropriate RH's at cooler temperatures, while humidification, if available, would protect against overly dry conditions in winter months. RH's for this space should vary seasonally according to the following guidelines:

**Summer:** Maximum RH 55%  
**Winter:** Minimum RH 30%  
**Spring/Fall:** Fluctuates between minimum and maximum values

It should be possible to maintain something close to these without major alterations to the system, and various methods will be explored below.

### Measured Reading Room Environmental Conditions

The conditions of ARS Reading Room are essentially the same as those of the ARS storage area. The reading room is an "administratively" separate space, and theoretically a separate conditioned space due to the presence of VAV B-5. The VAV box B-5 allows for terminal control of temperature separate from ARS storage. The temperature graph, shown below, illustrates that similarity. While expected, due to the lack of any real barrier between the two spaces (the wire cage wall is only contributes to security for the storage space), it serves as a limit to the conditions that can be held for storage alone. The dew points and RH's for the Reading Room match those of the storage area - all dehumidification occurs at AHU-2, and with the same temperatures, RH's also match.



## Preservation Assessment: As Found

The ARS storage space exhibits several challenges related to the design of AHU #2, its typical operation and set points, and the preservation demands of the collections housed in the zone. The materials stored in this area require cool to cold temperatures with control of RH as indicated above in order to minimize the rate of chemical decay (natural aging) and control mechanical damage (physical shape change) to the objects. For the data collected between January 2010 and early October 2012 we have the following metrics (a full description of IPI's preservation metrics is attached as an appendix):

Location Dataset	Date Range	Natural Aging	Mechanical Damage	Metal Corrosion	Mold Risk	T°F	%RH	DP°F	TWPI	%DC Max	%EMC Min	%EMC Max	MRF
ARS-Storage-A	2011-11-09 to 2012-10-03	OK	OK	RISK	GOOD	68.7	47	46.9	45	1.21	6.8	11.2	0
ARS-Storage-JJ	2011-11-09 to 2012-10-03	OK	OK	RISK	GOOD	67.6	49	46.9	46	1.33	7	11.8	0
ARS-Storage1 (old)	2010-01-13 to 2011-07-22	RISK	OK	OK	GOOD	69.6	46	48	42	0.74	7.6	10.2	0
ARS-Storage2 (old)	2010-03-09 to 2011-07-22	RISK	OK	OK	GOOD	71.3	44	47.9	41	0.79	6.9	9.7	0
Average (4 locations)						69.3	46.5	47.4	43.5	1	7.1	10.7	0

The rate of natural aging, represented by the Time-Weighted Preservation Index (TWPI), is 41-46 for the space, which is between the "okay" scale and "risk" – a score of 45 will generate a "risk" indicator, and the historical data shows the storage area as a "risk" for

chemical degradation. While this TWPI is fairly typical of collections storage environments – in terms of quality, it equates to a typical “human comfort” environment – given the significance of the collection materials housed in this space, that metric needs to be higher. The ARS space, as indicated above, has historically operated between 60°F and 75°F with fluctuating RHs between roughly 20% and 70%, which together determine the TWPI. By comparison, a space kept steadily at 55°F and 45% RH would yield a TWPI of 123. While we would not advocate for control and the cost of flatline conditions, this comparison usefully demonstrates that the improvement of the rate of natural aging is dependent upon colder temperatures and better control of relative humidity than are currently available. The particular risks of chemical degradation in this case are the breakdown of the plastics and releasing agents used in the molding of vinyl albums and the chemical decay of paper materials (including archives and record jackets) in the collection.

The moisture content of the environment determines the mechanical damage indicator, which shows as “ok” for the space. While this overall metric is acceptable, there are two negative factors at play in this assessment for the most recent data – typical summer RHs that are too high, leading to excessive moisture absorption in collection materials (indicated by the EMC Max, or the maximum equilibrium moisture content), and a wider range between the peak moisture content (high RH periods) and the low moisture, dry periods in winter (low RH periods), represented by the % dimensional change (% DC Max which is close to a risk rating of 1.5%). These measures indicate what was observed from the graphs of the data – that summer RHs are higher than desired, primarily due to higher dew points combined with lower temperatures than the dew point can support, and wide fluctuation between high summer RHs and low winter RHs. While observed low RH's are not showing a negative effect on the metrics, drier conditions than desirable are documented, although of brief duration. Correcting those would further improve the %DC metric. For the types of materials located in ARS – including the remaining cylinder recordings and the vinyl LP collection – these are potentially significant risks that can produce noticeable shape change and damage in audio collections, affecting both their physical integrity and sound quality.

Mold growth is not a primary concern in the ARS storage. While RH's occasionally approach 70%, the typical RHs in the space, while higher than ideal for physical damage, are not high enough to trigger mold growth.

The final metric, metal corrosion, which is based on RH levels, shows “risk” for the space due to periods of sustained relative humidity above 55%. In the case of ARS, this is of some limited concern - the metric primarily deals with corrodible metals, which while not common in most audio formats, may be part of the construction of historic playing devices. The majority of these devices are currently stored in the ARS Reading Room, not in the storage area.

## AHU #2 (refer to system cartoon on page 14)

AHU #2 provides the climate for the ARS. Its performance was monitored from November 2011 until early October 2012. The objective was to determine the behavior of each component that can affect the climate in ARS. The components observed and their potential to affect the climate are as follows:

### **Return/Exhaust Fan**

This fan returns air back from the three portions of AHU #2's zone. It has a variable frequency drive (VFD) that is shut down, during unoccupied hours, for 95 hours per week.

### **Supply Fan**

This fan supplies air to the three portions of AHU #2's zone. It has a VFD that is shut down, during unoccupied hours, for 95 hours per week.

### **Outside Air Supply Duct**

This duct provides outside air to the system. A modulating damper controls the quantity of outside air that is allowed into the system at any given time. Original specifications indicate that the system was designed around a blend of 8% outside and 92% return air. The current minimum outside air set point is 30%.

### **Economizer**

While not a physical component, the design of AHU #2 does allow it to operate in what is called an "economizer" mode, which uses quantities of outside air as free conditioning when the outdoor conditions match the defined indoor set points. Three sets of dampers, at the outside air duct, the return air duct, and the exhaust air duct, modulate in order to change the proportion of return or outside air that is used by the system. The economizer currently runs off of a temperature control to use varying amounts of outside air when the outside air temperature is closer to the desired cooled air temperature than the return air temperature. Of particular significance for preservation concerns is the fact that there is no moisture component to the control of the economizer - meaning that it is possible to bring in outside air that may be too damp or too dry for preservation. Adjusted operation of the economizer will be discussed in potential operations strategies.

### **Supply Air Temperature Control**

The outdoor air temperature, according to the following table, determines the supply air set point for the system:

OA = 50°F	SA = 65°F
60°F	65°F
70°F	62°F
80°F	62°F
90°F	59°F

The terminal VAV's in each space can still modulate dampers and/or heat the supply air to meet individual space demands.

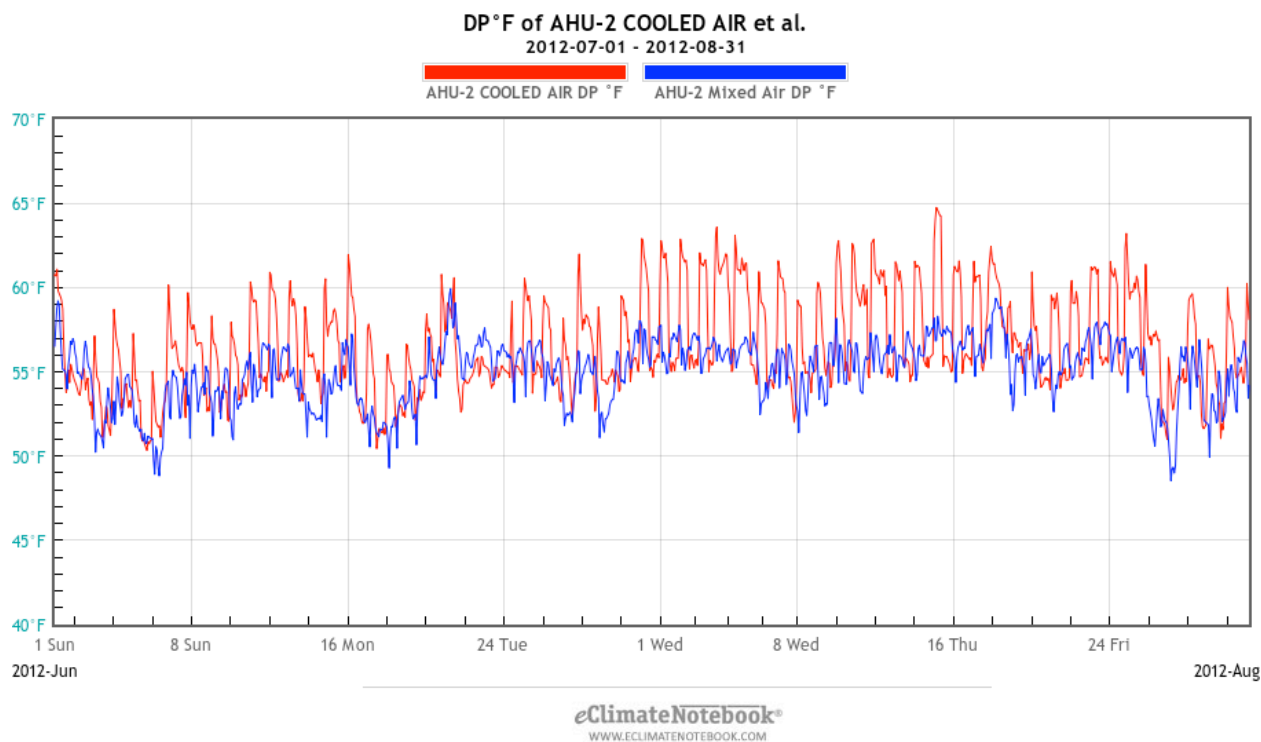
### **Cooling Coil**

The cooling coil is designed to cool 21,750 CFM of entering air from 76.3°F and 52.6% RH (dew point 52.6°F) to a leaving air condition of 56°F and 88.2% RH (dew point of 52.6). The designers assumed an entering chilled water temperature of 46°F. These design specifications indicate that the purpose of the unit, as designed with identical entering and leaving dew point conditions, was primarily for temperature control, rather than dehumidification.

The measured performance of the cooling coil during the summer of 2012 (defined here as June through September) indicates entering air of approximately 71°F at 55% RH (dew point of 54.1) and leaving air of 57°F at 83% RH (dew point of 52). A comparison of design versus actual cooling is as follows:

	<i>Degrees of Sensible Cooling</i>	<i>Total Cooling (Sensible &amp; Latent)</i>
<b>Design</b>	20.3°F	4.9 Btu/lb. of air
<b>Actual</b>	14°F	4.2 Btu/lb. of air

This example uses estimated averages of entering and leaving conditions of air when the coil is operating; a true average of the air conditions in the data cannot be used due to the shutdowns, where conditions change but no energy is being used. The result is still valuable, and backs up both the data and the design. As shown in the graph below, the dew point after the cooling coil (red plot), which is used as a representation of work done by the coil, tracks closely with the dew point of the mixed air (blue plot) before cooling coil. While dehumidification does occur, it is of a limited nature and not consistent. The estimated actual leaving dew point of 52°F is in line with the design leaving dew point.



However, there is a slight shortfall in actual cooling achieved when considering the total cooling performed (difference in enthalpy of entering and leaving air conditions). The estimated actual total cooling in the above table is less than the design capability. Given that the temperature of the chilled water from the central plant is 43°F, three degrees less than the coil was designed to use, not only does the coil appear to not quite do all the work that it is capable of, but it also may well be capable of even more work than the design conditions call for.

**Note:** Getting the maximum possible dehumidification from the cooling coil in summer is critical to the climate in ARS. With an available chilled water temperature of 43° there is a very real possibility that a dew point better than 52° could be achieved. Any lower dew point temperature that could be achieved would provide better summer RH's, or could potentially allow for a cooler temperature to be maintained. During typical summer dehumidification months, the cooling coil valve should be 100% open when the unit is operating to achieve the best condition possible for preservation. Beyond the chilled water temperature, it is important that there be no obstructions to water flow through the coil and that the coil surfaces (water side and air side) be kept clean. **Maximum flow and clean coils should be a high operations and maintenance priority.**

### Reheat Coil

The reheat coil is designed to use hot water to add whatever heat is necessary to bring the cooled air up to the supply air temperature set point. The supply air set point, as described above, is supposed to be on a sliding scale according to outdoor

temperature conditions. The measured supply air temperatures leaving AHU #2 ranged from 62°F to 68°F, which reasonably matches the sliding scale. One discrepancy was found: at outdoor temperatures between 70°F and 80°F, the supply air set point should be 62°F. Instead, the measured supply air from the unit was more often at 65°F or above. Depending on the heat load and set points that those reheats are trying to control to, that additional reheat performed at AHU #2 may have a negative impact on total energy usage. Estimates were created using the measured cooled and supply air temperatures and the design quantities of air to determine the approximate quantity of reheating. They indicate that the coil typically reheats 21,750 CFM of air from a temperature of 57°F to 66°F during the summer months. Available winter data (a logger malfunction rendered some of the supply air data unavailable) indicates that normal operation heats 21,750 CFM of air from 59°F to 65°F.

### **Variable-Air-Volume Boxes (Terminal Reheat)**

A total of five VAV boxes serve the ARS reading room and storage areas in the basement of Braun. Each box is controlled by a thermostat in the space, and can adjust air conditions entering the space by either modulating a damper to reduce airflow or adding heat through a hot water heating coil. The original VAV that serves the ARS storage area, B-8, is designed to condition 1,920 CFM of air. Though specifications for the second VAV, B-8A, were not available, the unit should be of equal size or smaller given the size of the area it serves. For summer operation, data gathered in the supply air duct after the VAV's indicates that no additional reheat is being done. Data from winter operation indicates that the VAV typically provides 1°F to 2°F worth of additional heat.

### **Energy Usage: As Found**

The primary energy consumers in the system are the supply fan, the chilled water cooling coil, the hot water heating coil at the unit, and the hot water heating coils in the reheats. Quantities of work done at each coil (in degrees of temperature) are estimated based on graphed data, and take the system shutdowns into account:

<b>Supply Fan:</b>	\$10,266 per year (at kwh charge of \$.1095/kwh)
<b>Return Fan:</b>	\$2,186 per year (at kwh charge of \$.1095/kwh)
<b>Cooling Coil:</b>	\$30,600 per year (at FY 2013 price of \$.4335/ton/hr)
<b>Heating Coil:</b>	\$11,067 per year (at FY 2013 price of \$20.95/mlb steam)
<b>VAV Reheat:</b>	\$65 per year (at FY 2013 price of \$20.95/mlb steam) **Cost only estimated for VAV B-8 and B-8A, which serve the ARS storage area

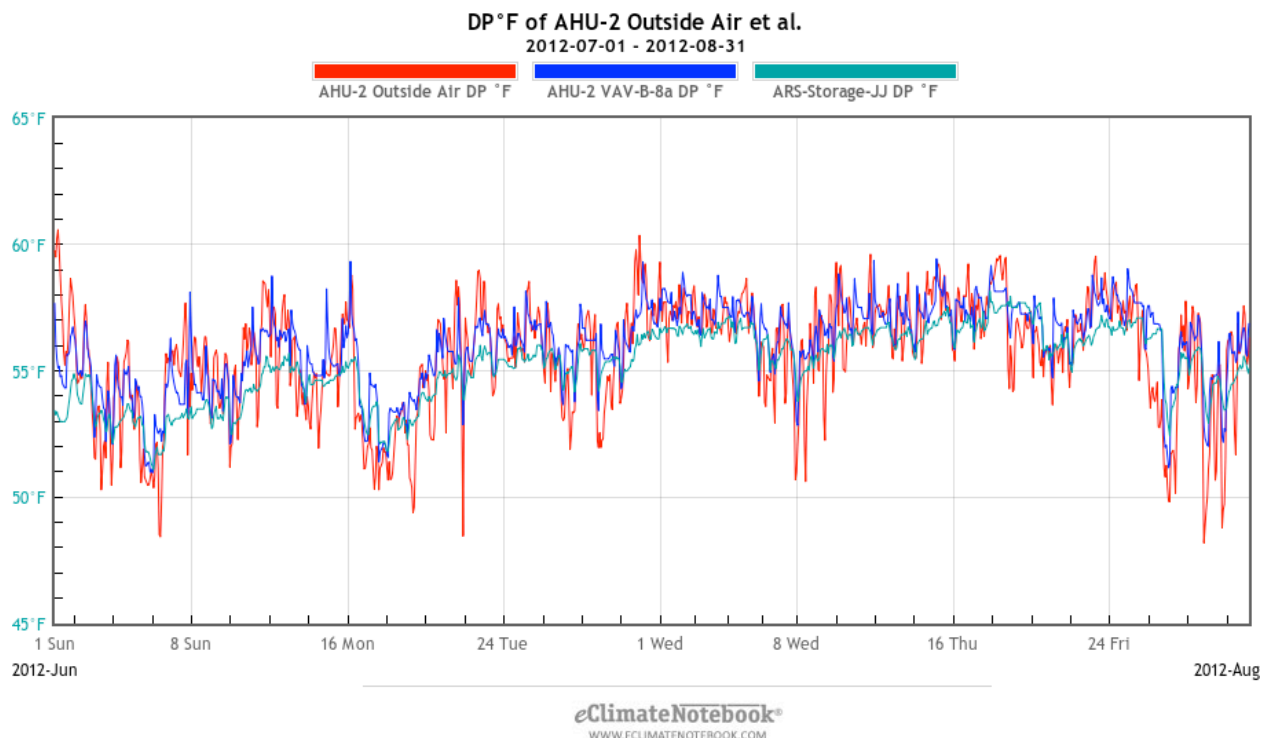


## Alternatives to Current Operation

The following are potential adjustments to the operation of AHU #2 that require little or no capital improvements to the existing mechanics. Because of the arrangement of the system and the extent of the zone that it serves, there is a low probability that these strategies will affect human comfort in other portions of the building. However, if any of these alternatives are implemented, they should be evaluated during a testing period to check any impact on other parts of the system's zone.

### A. Lower AHU #2 supply summer dew point temperature for preservation improvement

As discussed earlier in the report, AHU #2 does not currently dehumidify outside air effectively or consistently. An inspection of dew point graphs for outside air, the VAV B-8A supply air (the last air condition available before it is supplied to the space), and the space dew point for July and August 2012 shows two issues: the dew point in the space varies from 52°F to 58°F, with more time spent at the upper portion of that range, and there are numerous occasions where the indoor dew point is equal to or greater than the outdoor dew point, indicating no dehumidification at those times. These higher summer dew points severely restrict the ability to hold quality preservation conditions within the ARS storage area. At an average dew point of 55°F, the coolest temperature reasonable for preservation is 70°F with an RH of 60%. These conditions result in a TWPI of 30 - not acceptable for a recorded sound collection of this caliber.



Improving the dew point temperature for the ARS storage would mean achieving the maximum dehumidification possible from the cooling coil at AHU #2. As discussed earlier, the coil, based on estimated calculations, does not quite operate to its full design capacity for total cooling, and as the graph shows, rarely produces the 52° summer dew point that it should be capable of. The entering mixed air conditions seem to reasonably match the assumptions made in the original design, but the availability of 43°F chilled water supplied to the cooling coil, which is 3°F colder than the design calculations planned for, should increase the dehumidifying capacity of the coil.

To achieve this, the cooling coil valve should be 100% open to supply chilled water whenever dehumidification is called for. Experimenting with this control will determine what the actual dew point capability of the coil is based on current information. Once that dew point is determined, it can be used to select an appropriate temperature set point for the ARS storage area. During the summer of 2012, the temperature in ARS was typically around 70°F, resulting in RH's that were consistently in the low 60%'s and a TWPI of 31. A consistent dew point of 51°F would allow for a temperature set point of 68°F (at the low end of human comfort, but reasonable) with an RH of 56% and a TWPI of 37 – an almost 20% increase in preservation quality.

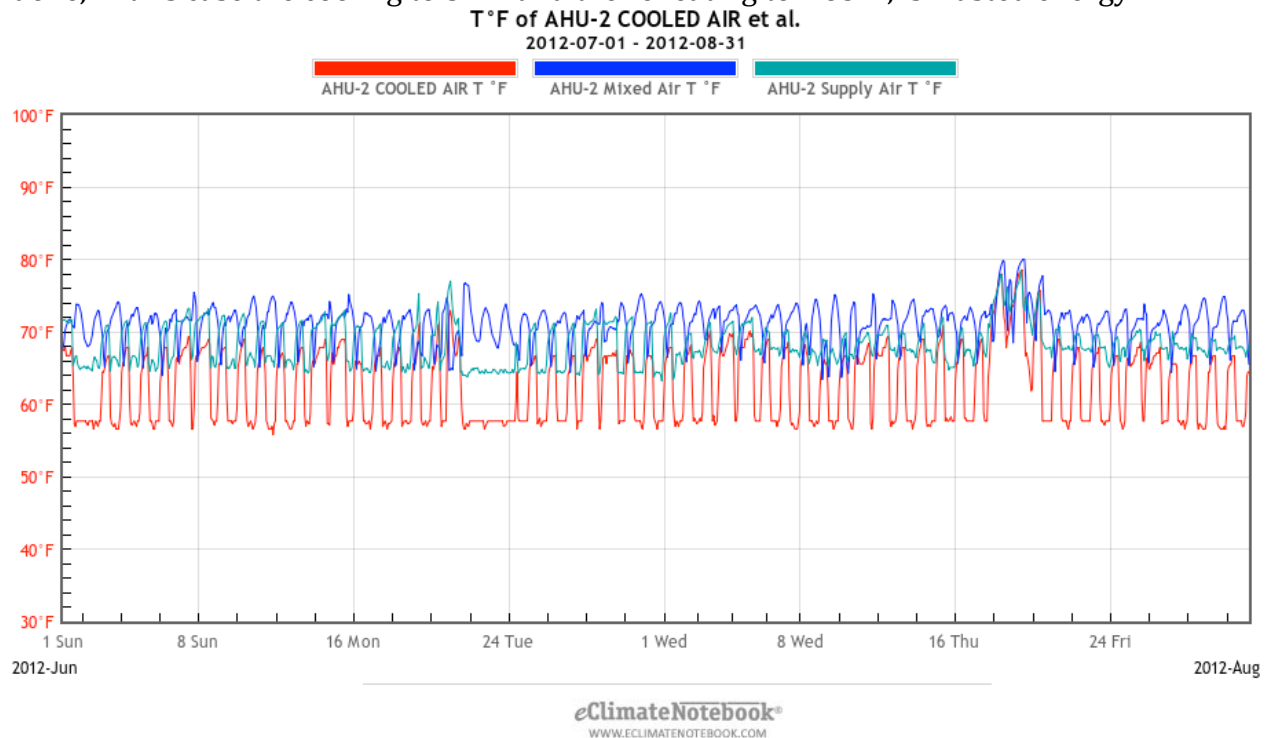
Two other factors working against improved dehumidification at the AHU #2 cooling coil are the current set point of a minimum of 30% outside air and the temperature-only control of the economizer. Outside air typically works against dehumidification in the summer months; in the above dew point graph it is a rare occasion when the dew point of the outside air meets the desired indoor dew point of 51°F. The more that is brought in, the more work the cooling coil must perform to remove that moisture, compared to a situation where outside air is set to 10%, meaning that 90% of the air hitting the cooling coil has already been dehumidified once. Similarly, while the economizer control works for free "cooling" based on sensible temperature, the lack of moisture consideration in that control means that it is quite likely that excess moisture is being brought in along with the cool air. Steps to identify whether the percentage of outside air could be reduced and to add a dew point control to the economizer – where air could be brought in if it met the temperature set point and was at a dew point of less than 51°F – would have the potential for significant savings if efforts were made to improve dew point control at the cooling coil.

This action should require little to no capital investment in equipment or space redesign. Potential negatives include increased energy usage at the AHU #2 cooling coil and at the downstream VAV reheats associated with occupied spaces elsewhere in the zone.

## **B. Optimize summer dehumidification at AHU #2 for energy savings (can be done independently or in conjunction with Alternative A)**

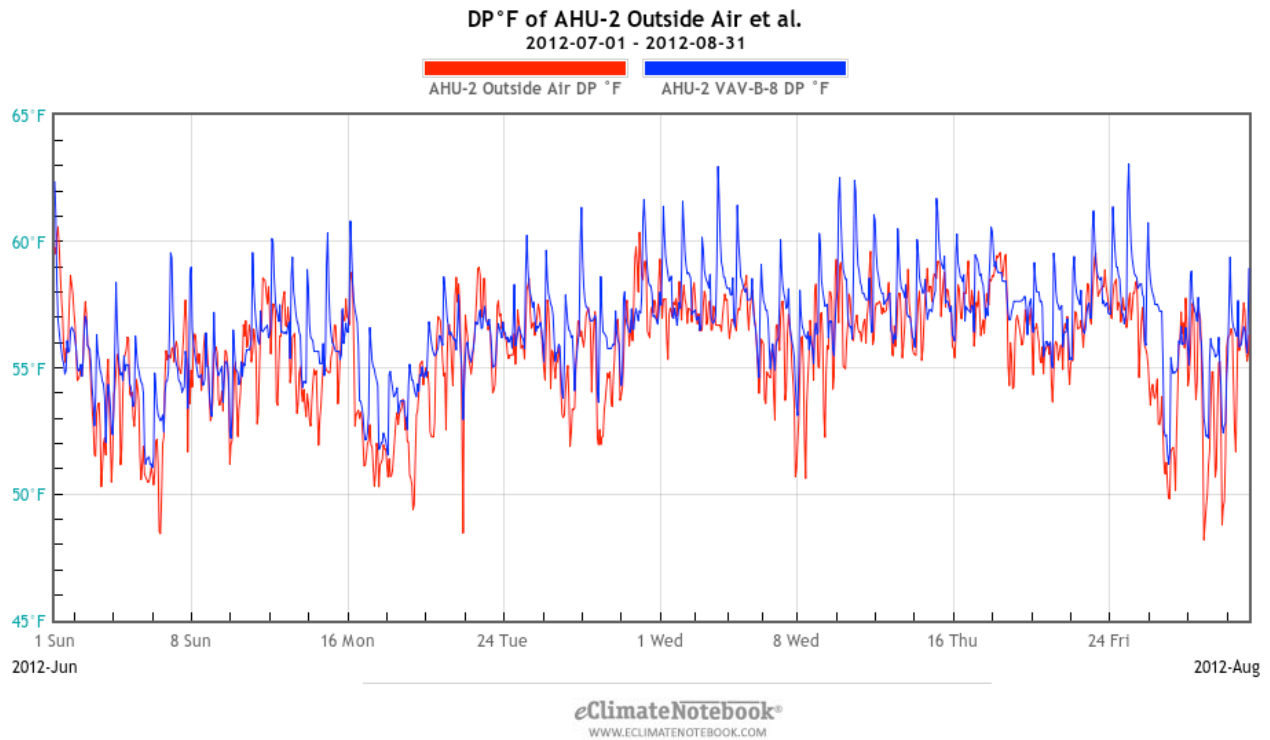
Inspecting a temperature graph (shown below) shows that the cooling coil currently **always** subcools (ie, cools lower than is necessary for simply meeting supply air temperature) during summer operation – **regardless of whether it is actually**

**dehumidifying.** The purpose of a subcool and reheat system is to subcool the incoming air temperature down below its dew point in order to dehumidify, and then to reheat that air to an acceptable condition to supply to the space/VAVs. If no dehumidification is occurring – whether due to low outdoor dew points or to insufficient dehumidification capability at the cooling coil – there is no purpose in subcooling the air. The only work necessary is the sensible cooling of the temperature to the supply condition necessary. Any other work done, in this case the cooling to 57°F and the reheating to ~63°F, is wasted energy.

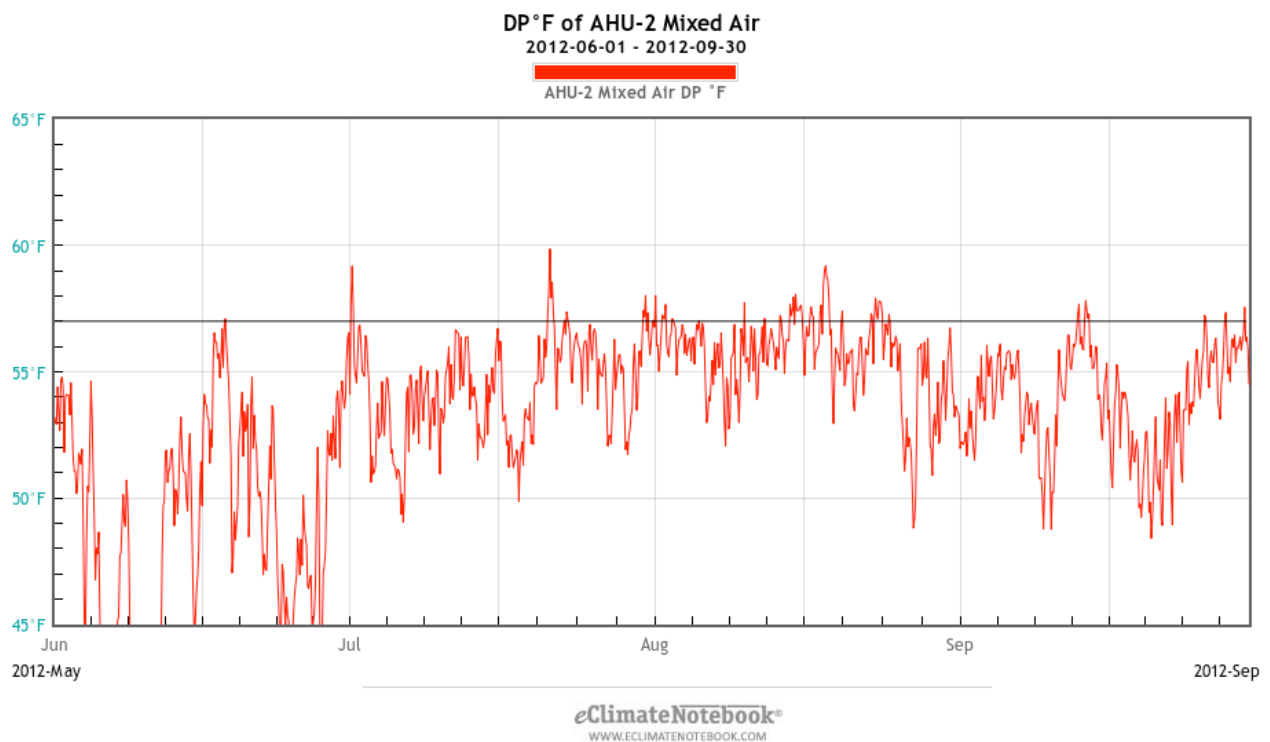


Regardless of whether or not the operational changes in Alternative A are made, improving the cooling coil control to only subcool when the incoming mixed air dew point is higher than the cooling coil discharge set point has the potential to save a significant amount of energy. The dew point graph below shows the dew point condition of the supply air leaving B-8 VAV, and the outdoor dew point during July and August 2012. There is a significant portion of the time when the dew point of the supply air is higher than the dew point of the outdoor air, indicating that no dehumidification has occurred at the coil, and the subcooling behavior, shown above in temperature, is wasted energy.

The summer operation of the cooling coil currently appears to run based on satisfying a 57°F discharge set point from the coil. An example of one method to eliminate the excess subcooling would be to program the controller to only subcool to 57°F if the incoming dew point from the mixed air is 58°F or higher. If the incoming dew point at the mixed air is 57°F or lower (which the coil, based on current operation, would have no chance of dehumidifying), then the coil should only sensibly cool enough to satisfy the AHU #2 supply air (discharge) temperature, eliminating excess cooling and reheating.



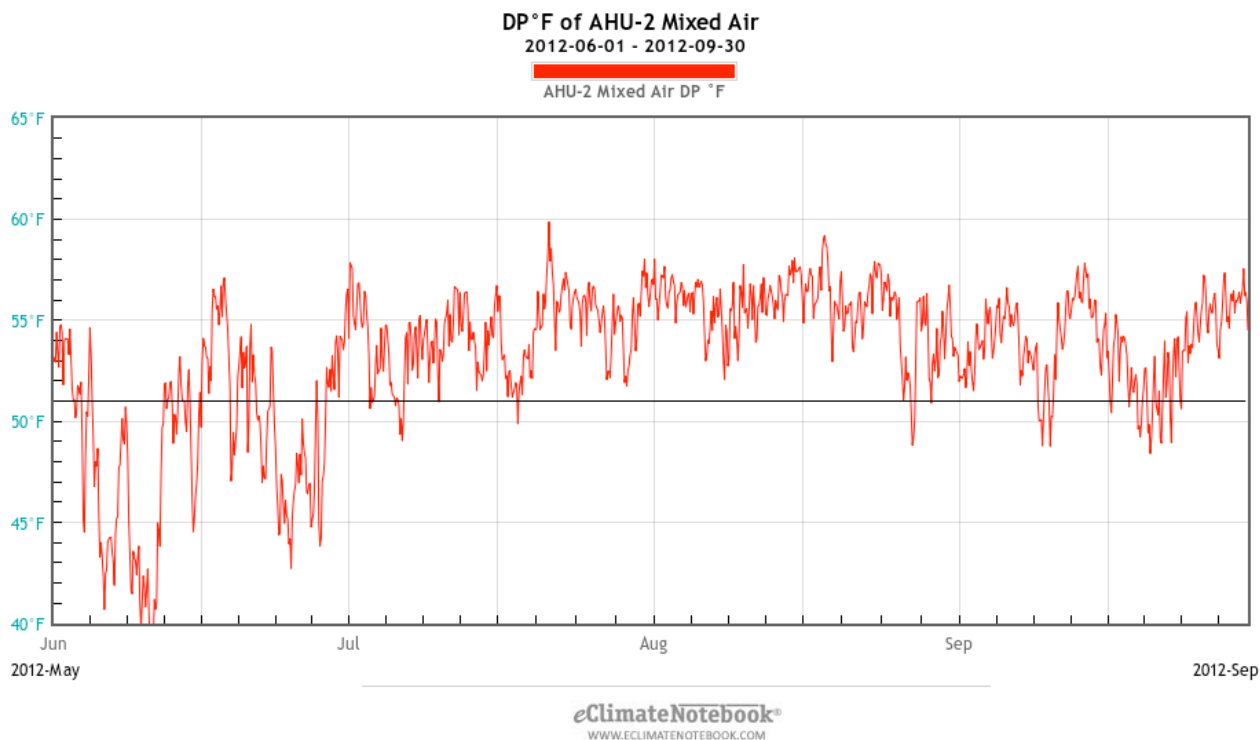
The dew point graph below shows the incoming dew point of the mixed air, with a 57°F limit line overlaid to represent the current cooling coil operation. This graph helps to visually quantify the potential of correcting the excessive subcooling.



In this model, the only time the system would use the energy necessary to subcool/dehumidify is when the conditions are above that limit line. For all the times

below the line, the system would only sensibly cool the air, resulting in significant energy savings at the cooling coil.

Combining this energy optimization with the improved dew point for preservation described in Alternative A would have less of an impact on energy savings, but would still work. The graph below provides an idea of how often the system would actively dehumidify based on achieving a dew point of 51°F at the cooling coil between June and the end of September – the system would subcool/dehumidify during the times above the limit line, and only sensibly cool (saving energy) during the times below the line.



Enacting this additional control over the cooling coil operation should not require any significant capital costs or improvements, although it would require installing a temperature and RH sensor in the mixed air if one is not already present. Because there is no impact on the final discharge air temperature from AHU #2, there would be no influence on human comfort or energy usage downstream. Solely enacting the improved control without lowering the dew point would have no effect on preservation quality for the space, but would lower energy usage at the coil.

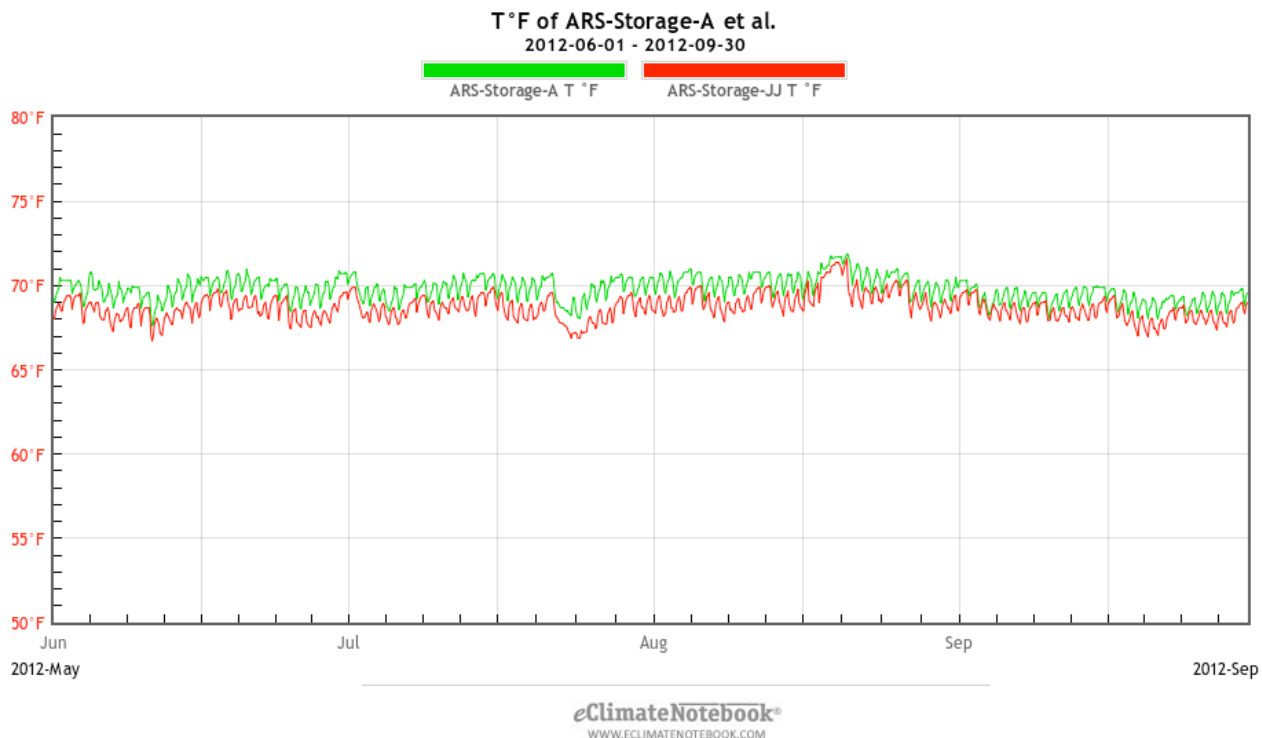
### **C. Experiment with increased duration of shutdowns for energy savings**

Stanford's Department of Sustainability and Energy Management currently shuts down AHU #2 for 95 total hours per week, primarily during unoccupied hours. This already represents an approximately 56% savings over the fan energy that would be incurred at AHU #2 if it were to run constantly, as well as significant savings at the cooling and heating

coils. The below graph illustrates the impact of those shutdowns on the temperature in the ARS storage area during the summer months between June and the beginning of September in 2012, the most difficult time of the year to hold space conditions. Nightly fluctuation ranges from 1°F to 1.5°F, with fluctuation during the longer weekend shutdowns typically varying by up to 2°F. In nearly all instances, the system recovers to the previous day's set point without any problem.

This amount of fluctuation poses very little real threat to the preservation quality of the environment or to the long-term preservation of the materials. The effect on TWPI (the rate of chemical degradation) is minimal, and current research is showing that, while the temperature equilibration of objects subjected to changes in conditions typically occurs within no more than 24 hours, the density of the stored material and the duration of the shutdowns indicates that the objects probably never "feel" the full effect of the temperature variation.

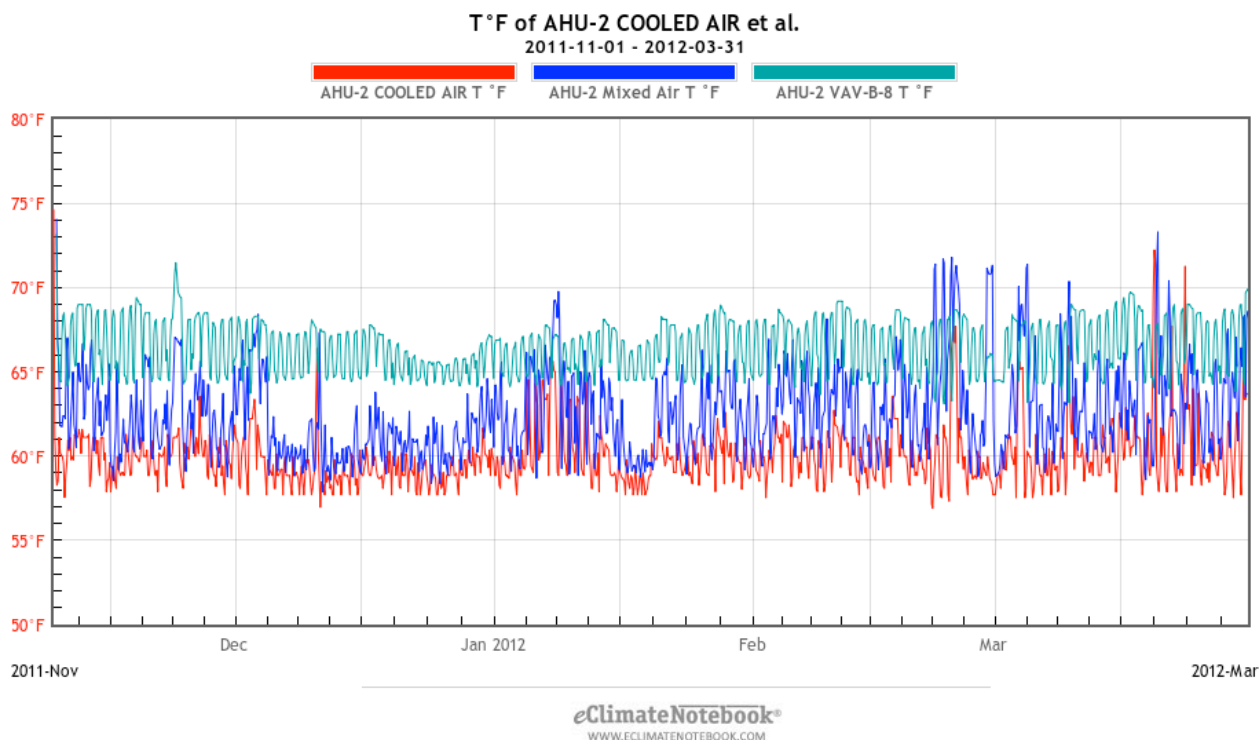
Experimenting with these altered schedules would require continued monitoring of the collections space to determine any additional effect of the shutdown on the temperature of the preservation environment. If fluctuation levels are still acceptable to the preservation mission (2°F to 2.5°F should pose no serious threat to preservation, as long as the system recovers to its set point), the increased shutdown time would contribute an additional 4% energy savings to the fan energy for one additional hour nightly, and an additional 9% over current operation if increased by two hours nightly. This adjusted operation would require no additional capital cost or equipment; it is simply an adjustment to an already running schedule.



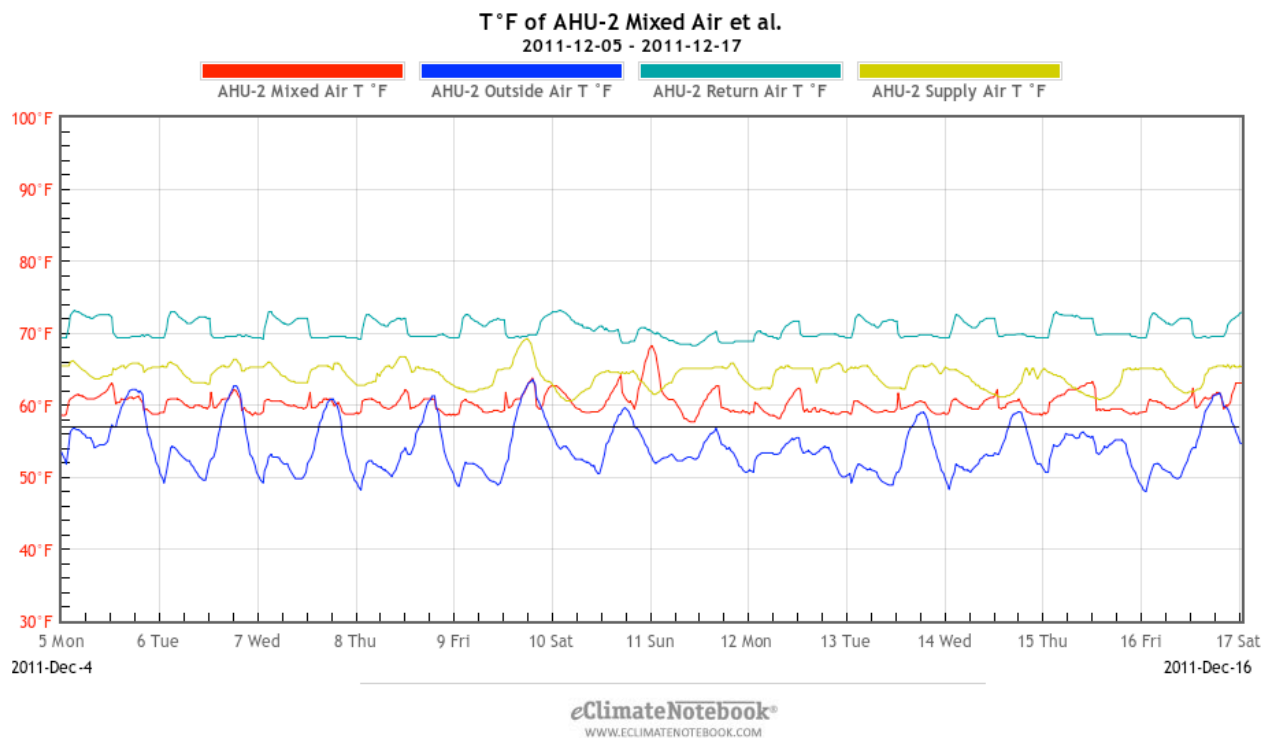


## D. Correction of AHU-2 winter cooling behavior for energy savings

The graph below shows the recorded behavior of AHU #2 during the winter of 2011-2012. While the readings may be slightly off due to the placement of the logger in the airstream (the logger may not be reading a perfect blend), winter operation of the unit appears to cool the mixed air stream by approximately 1.5°F before reheating it at the heating coil in the unit or at the downstream VAVs. During the winter season, this cooling is wasted energy – all that is necessary is the sensible heating of the mixed air temperature to the necessary supply air set point. Correction could be as simple as checking the cooling coil valve for leaks or setting the valve control to only open if the mixed air temperature is higher than the desired supply air temperature from AHU #2. If the behavior is confirmed and corrected, the winter savings in cooling energy would be approximately \$1,860 based on energy calculations performed for the unit's winter operation. This change would have no impact on conditions felt in the spaces.



Additionally, current economizing behavior appears to waste energy during portions of the winter months. The graph below shows that the blend of the return air and outside air results in a mixed air condition that is colder than the supply air temperature. Reducing the amount of outside air in this scenario (it appears to be using more than the 30% minimum), and only using enough outside air to cool the return air to the necessary supply air condition would reduce the amount of work done by the reheat coil, saving a significant amount of energy.



## Summary

The options listed above represent the best possibilities for improving preservation and energy savings without excessively harming either goal. Other possibilities, such as holding a cooler temperature in the ARS in winter, were explored, but ultimately determined to be counter-productive. The primary stumbling block is the fact that in order to achieve better conditions for ARS storage – which uses roughly 15% of the total air volume supplied by the unit – work must typically be done to 100% of the air that the unit supplies. Put simply, there is no good way to make a marked improvement in the preservation quality of the environment for ARS without significantly increasing the energy costs. The options given below are therefore separated as possibilities for preservation improvement and possibilities for reduction of energy costs.

To improve preservation in ARS with adjusted operation at AHU #2:

- Work to achieve a consistent 51°F dew point from AHU #2 during dehumidification season (April through October) by ensuring that the cooling coil valve is 100% open when mixed air dew points are higher than 51°F, possibly reducing the minimum amount of outside air, and adding a dew point control component to the economizer control to only bring in additional outside air when the temperature set point is met and the outside air dew point is less than 51°F;
- This approach will only result in an approximately 20% improvement in the preservation environment, and still will not improve conditions to an acceptable level for the rate of chemical degradation;



- This approach will also likely result in a significant increase in energy usage at both the cooling coil in AHU #2 as well as at the downstream reheats.

The best-case scenario for optimization at AHU #2 to maintain the current quality of the preservation environment and reduce energy expenditure, without capital improvements includes:

- Improving subcool/reheat control to ensure that the subcooling is only performed when the dew point of the incoming mixed air is higher than 57°F (this strategy could also be applied with the above preservation improvement, with an incoming dew point above 51°F, with less impact)
- Experimenting with expanding the nightly shutdowns by one to two hours to further reduce energy usage; and
- Confirming and correcting unnecessary cooling behavior at the cooling coil and economizer during the "winter" months (November through March).

## RECOMMENDATIONS FOR CAPITAL IMPROVEMENTS

Recommendations for capital improvements to the system and environment in the ARS storage area are based on two primary goals – the improvement of the preservation environment for long-term collections preservation and separating the work done to create this environment from the rest of the current AHU #2 zone. The capability of the current system is not sufficient to reach appropriate preservation goals for the collections, and even if the current system were capable, the energy cost of creating those conditions for such a small portion of the zone is prohibitive. A small, separate air handling unit specifically designed to create the necessary preservation environment for the ARS storage, and adjustments in the way the actual physical ARS storage space is used are the best options for reaching an optimal preservation and energy balance in that space.

The goal is to create an environment that is beneficial to the collection, reasonable given the campus setting, and that takes advantage of the external weather conditions as much as possible. While the material would certainly be better off for preservation in a space that was at 50°F and 35% RH, that goal would be better achieved by moving the material to SAL3, not by trying to create that environment in ARS. However, in order to achieve the public service mission, not all materials can be moved to off-site storage, and parts of the collections must remain accessible on campus in ARS. The goal therefore, is to improve the preservation environment in ARS as much as reasonably possible.

Recommendations are based on the following seasonal goals for the preservation environment and take into account the current available chilled water temperature of 43°F:

Summer:	Temperature:	60°F
	Relative Humidity:	55%
	Dew Point:	45°F

Winter:            Temperature:        60°F  
                     Relative Humidity:    Min: 35%  
                     Dew Point:                33°F.

These set points would result in a summer preservation index (PI) of 63, which is double the quality of the current summer environment, and winter PI's of 110 at the minimum RH.

If 60°F were determined to be too cold for human comfort in the ARS storage area (even with reduced human occupation in the space), an increase to a year-round set point of 62°F would result in the following seasonal conditions:

Summer:            Temperature:        62°F  
                     Relative Humidity:    52% RH  
                     Dew Point:                45°F  
                     Preservation Index:    60

Winter:            Temperature:        62°F  
                     Relative Humidity:    Min: 35%  
                     Dew Point:                34°F  
                     Preservation Index:    97.

This higher set point would result in reduced preservation quality (compared to a 60°F set point) and would also cost slightly more in energy consumption than a 60°F set point in summer due to increased need for reheat. This potential for a higher temperature set point does not change the design goals listed in Recommendation 3.

### **Recommendation 1: Physically separate ARS storage from the rest of AHU #2's zone.**

ARS storage and the ARS reading room are currently only separated from one another by a "cage"-type wall, which allows uninhibited air flow between the two spaces. With this arrangement, it is impossible to change environmental conditions in ARS storage without also affecting the reading room area. By adding an insulated wall between the ARS reading room and ARS storage area, it would allow for separate conditions to be maintained in the storage area, and would reduce any heat load from the reading room space. This improvement is necessary to maintain the conditions recommended above.

### **Recommendation 2: Reconfigure ARS storage as unoccupied space.**

ARS storage currently serves as the primary work space for one part-time employee, which effectively limits the range of acceptable environmental conditions to those within a human-comfort zone. By relocating this workstation to another area, such as the reading room space – which has been discussed with ARS staff – it would make the ARS storage an unoccupied area. Two benefits that would stem from this include the ability to maintain lower temperature conditions for collections preservation and possibly the ability to

reduce the amount of outside air required in the space. This movement of work space is likely necessary to achieve the conditions recommended above and increases the likelihood of optimizing energy savings at the new unit.

### **Recommendation 3: Install a new AHU to serve only the ARS storage area.**

As mentioned, there are three primary issues with the improving the preservation environment in ARS with the current AHU #2:

- AHU #2's design dew point capability of 52°F (perhaps 51°F given current chilled water temperature) is not sufficient to gain any real improvement in preservation conditions
- Any changes made at AHU #2 have to be made at to the entire air stream, resulting in a large increase in energy usage
- ARS storage is currently an occupied space with uninhibited air flow to the reading room.

The separation of the work space and the storage space, as discussed above, would mean that a new system installed to only serve ARS would be able to concentrate on creating the necessary environment for the collection in the most efficient manner, without having to worry about its effect on human comfort in the ARS reading room or the rest of the building.

One of data points gathered throughout the project was at the outside air intake to AHU #2. From an air conditioning and preservation environment perspective, Palo Alto experiences two main "seasons" that help define the goals for the indoor preservation environment. A warm, moist period from April to October, with a median temperature and dew point of 72.3°F and 56.4°F, respectively, is the primary concern for cooling and dehumidification, when achieving reasonable space conditions is more energy intensive. The design goals for this period should be:

Temperature:	60°F
RH:	55%
Dew Point:	45°F

From November through March, the area experiences a cooler period with a median temperature of 59.5°F and dew point of 39.1°F, though both conditions range widely. The design goals for this period should be:

Temperature:	60°F
RH:	minimum 35%
Dew Point:	33°F

From an energy perspective, these design set points take into account several factors. A summer dew point goal of 45°F should be easily attainable with an entering chilled water temperature of 43°F, does not require any additional dehumidification ability through the use of glycol or desiccant dehumidification, and still provides the opportunity for significant improvement in preservation. By setting the winter RH set point at a minimum of 35%, it satisfies the preservation goal while reducing the amount that the humidifier would need to be used compared to a higher RH set point. During in-between periods,

when the dew point is between 33°F and 45°F, as long as the 60°F space temperature is maintained, the RH will fluctuate between roughly 35% and 55%. Research has shown that most materials (including those in the ARS collection) can experience constant RH fluctuation between roughly 30% and 60% without experiencing any permanent mechanical damage.

For preservation, these design set points provide improvement for preservation in both summer and winter. The summer TWPI measured in 2012 was 31; if the recommended design set point were held in the space, the preservation index would be 63, or double the quality of the current summer preservation environment. While holding 60°F/35% RH constantly in winter would not be the goal, whenever the space did match those conditions it would result in a preservatin index of 110, or nearly 60% better than the preservation conditions experienced in the winter of 2011/2012.

Basic operation should be:

- Minimum outside air: 0% minimum if possible (the space is unoccupied). From an energy perspective, less outside air is better unless economizing conditions are met.
- At a mixed air dew point greater than 45°F: the unit dehumidifies and reheats to maintain a 60°F space temperature set point.
- At a mixed air dew point less than 33°F: the unit humidifies to maintain a 35% RH space set point and sensibly cools or heats to maintain a 60°F space temperture set point.
- At mixed air dew point between 33°F and 45°F: the unit only cools or heats to maintain a 60°F space temperature set point. The RH in the space will fluctuate between roughly 35% and 55%.
- Economizing (introduction of more than the minimum amount of outside air) should only occur if the outside air dew point is between 33°F and 45°F, and if the outside air temperature is less than the supply air temperature needed to maintain a 60°F space temperature set point. Looking at the outside air data, the opportunities for economizing based on the recommended space set points are probably limited.

Based on the shutdown data shown in Alternative C, it is very likely that any new unit installed to handle the ARS storage area may not need to operate constantly to maintain the space. Experimentation should be conducted with system shutdowns to find out if there are appropriate times where the system can be turned off for energy savings without adversely affecting the preservation environment. Likewise, if variable frequency drives are included in the system design, it may be possible to reduce air flow, particularly during the winter season, without harming the preservation environment.

Components in a new system design may include:

- Return/Exhaust Fan
- Rough and fine particulate filers (no need for gas-phase filtration)
- Cooling coil designed to achieve 45°F dew point based on 43°F entering chilled water temperature

- Heating/reheat coil
- Humidifier
- Supply Fan
- Variable Frequency Drives
- Economizer control based on temperature and dew point (not enthalpy)

## APPENDIX A – IPI’S PRESERVATION METRICS

### Chemical Decay



#### Measures:

The effect of the environment on metal corrosion. The % EMC max represents the maximum amount of moisture that was present in hygroscopic collection materials. Because metallic corrosion is dependent on available moisture, the % EMC gives us an idea whether or not metallic objects (mainly ferrous metals) would corrode in such an environment.

#### Applies to:

Metals or materials with metal components

TWPI Value (years)	Interpretation
$\geq 75$	GOOD
45-75	OK
$\leq 45$	RISK

### Mechanical Damage



#### Measures:

Three aspects of moisture content that promote mechanical or physical damage:

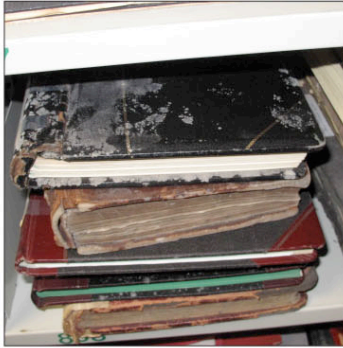
1. Max % EMC: Is it too damp? Will paper curl? Will emulsions soften? Will wood warp?
2. Min % EMC: Is it too dry? Will paper become brittle? Will emulsions crack?
3. % DC: How great are the fluctuations between the most damp and the most dry? Has expansion and contraction - from absorption/desorption of water - put physical stress on the collection materials?

#### Applies to:

Metals or materials with metal components

% Min EMC, % Max EMC and % DC	Interpretation
Min EMC $> 5.0$ AND Max EMC $< 12.5$ AND DC $< 0.5$	GOOD
Min EMC $> 5.0$ AND Max EMC $< 12.5$ AND DC $< 1.5$	OK
Min EMC $< 5.0$ OR Max EMC $> 12.5$ OR DC $> 1.5$	RISK

## Mold Risk



### Measures:

The risk for growth of the xerophilic mold species on collection objects or in collection areas.

### Applies to:

All organic materials (paper, textiles, plastics, dyes, leather, fur) or inorganic materials with organic films

**Note:** There is no "OK" rating for mold risk. At a MRF of 0.5, conditions are appropriate for germination of spores. By alerting RISK of mold growth at germination, the user is aware of the potential of mold growth before any visible or vegetative mold will appear. This allows for time to react and prevent formation of vegetative mold.

Mold Risk Factor	Interpretation
$\leq 0.5$	GOOD
$> 0.5$	RISK

## Metal Corrosion



### Measures:

The effect of the environment on metal corrosion. The % EMC max represents the maximum amount of moisture that was present in hygroscopic collection materials. Because metallic corrosion is dependent on available moisture, the % EMC gives us an idea whether or not metallic objects (mainly ferrous metals) would corrode in such an environment.

### Applies to:

Metals or materials with metal components

% EMC (max)	Interpretation
$\leq 7.0$	GOOD
$\geq 7.1$ and $\leq 10.5$	OK
$\geq 10.6$	RISK



## APPENDIX B – NOTES ON ENERGY CALCULATIONS

All energy calculations performed for this report are based on the following rate information either provided by or calculated from data provided by Stanford University:

<i>Electrical</i>	<i>Cooling</i>	<i>Heating</i>
<b>Commodity:</b> \$0.1095/kwh	\$0.4335/ton/hr of chilled water (FY 2013)	\$20.95/Mlb of steam (FY 2013)

Energy calculations are based on the following data, which was either provided by the design specifications for the system, measured by dataloggers within the mechanical systems or space, or calculated based on one of those two sources:

### Electrical

- Amp usage of motor
- Time of operation
- Cost rate of either commodity or demand

### Cooling

- Volume of air
- $\Delta T$  in °F across the coil(s) (amount of work done to the air)
- Time of operation
- Unit conversion factor
- Cost Rate

### Heating

- Volume of air
- $\Delta T$  in °F across the coil(s) (amount of work done to the air)
- Time of operation
- Unit conversion factor
- Cost rate



**Final Report  
PF-50169-11**

**Planning: Upgrading Climate Control to Preserve  
Audiovisual Collections**

**Shelving and Storage for Archival Sound Recordings**

**Project Director: Michael A. Keller**

**Stanford University**

**February 2013**

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## 1. Introduction

Sound recordings have changed formats several times since their invention in 1877. While there have been many studies on the storage of books and paper materials, there has been far less research on the optimal techniques for storage and shelving of sound recordings. Many libraries have deaccessioned older recording formats in favor of current technologies such as compact discs. However, research collections and archives still hold older recordings in a variety of formats which require storage and maintenance. This paper attempts to address and offer solutions for shelving these materials for long-term use and preservation. As such the paper will focus on the physical aspects of storage. The practices suggested here rely on information found in the published literature and on the experience of the Library of Congress in building the National Audiovisual Conservation Center completed in 2007. Other recommendations are the result of the staff experience at the Stanford University Archive of Recorded Sound. Many of the techniques and designs used for shelving are the result of years of trial and error in addition to scientific research about the storage of audio-visual materials. Issues of environmental controls and lighting, although related to physical storage, are beyond the scope of this paper.

## 2. Major Published Literature on Sound Recording Shelving

The work of A.G. Pickett and M.M. Lemcoe, *Preservation and Storage of Sound Recordings*,<sup>1</sup> is the classic study of the topic. It is a scientific study of the chemical composition and physical properties of sound recording discs and magnetic tape manufactured up to 1959. Their work includes specific recommendations concerning shelving and storage of discs and magnetic tape. Much of the study is still valid today, but does not deal with later sound recording technologies or cylinders. General advice based on Pickett and Lemcoe and the experience of archivists is covered in a section of *The Preservation and Restoration of Sound Recordings* by Jerry McWilliams for all major formats of recordings through 1979.<sup>2</sup> Shelving for music libraries was covered in a chapter in *Shelving Capacity in the Music Library* by Robert Michael Fling.<sup>3</sup> Fling addresses shelving for LP and reel-to-reel tape, which were the primary formats collected by most libraries when the book was published in 1981, but does not cover earlier formats such as cylinders or 78 rpm discs. Nor does it cover later formats such as audiocassettes, which were in common use at the time, or compact discs, which were not yet available. The most comprehensive source from the digital age is the article, "Storage of Sound Recordings," by Richard Warren, Jr.<sup>4</sup> Literature about shelving for sound recordings after the 1990s appears to be fragmentary and scattered between articles on the care and handling of recordings and the literature on library and archives building and design.

<sup>1</sup> A. G. Pickett and M. M. Lemcoe, *Preservation and Storage of Sound Recordings: A Study Supported by a Grant from the Rockefeller Foundation* (Washington: Library of Congress, 1959).

<sup>2</sup> Jerry McWilliams, "Storage," in *The Preservation and Restoration of Sound Recordings* (Nashville: American Association for State and Local History, 1979), 22-54.

<sup>3</sup> Robert Michael Fling, "Recordings," in *Shelving Capacity in the Music Library*, MLA Technical Reports, no. 7 (Philadelphia: Music Library Association, 1981), 18-31.

<sup>4</sup> Richard Warren, Jr., "Storage of Sound Recordings," *ARSC Journal* 24, no. 2 (Fall 1993): 130-175.

### 3. General Principles

#### 3.1 Storage Methods

There are at least three main ways to store sound recordings: on shelves, in cabinets, or in boxes arranged on shelves. Standard library shelving can be used for some sound recording materials. However, custom designed shelving and cabinets are necessary for some sound recording formats, because of the special size and weight requirements of these materials. The option chosen depends on the format of the material, the quantity of a particular format in the archives, the availability and configuration of space within the facility, the need to interfile materials, and ease of accessibility. In general, materials are segregated by format and size to save space, keep like categories of materials together, and insure appropriate environmental controls for long-term preservation. Different room sizes, shapes, and ceiling heights will dictate not only the layout of shelving ranges but also shelving lengths and heights. Local building codes may call for additional requirements than those discussed below. The American's with Disabilities Act (ADA) will also dictate issues governing accessibility of the materials and such issues as aisle width.

#### 3.2 Shelving

##### 3.2.1 Stationary Shelving

There are at least three types of adjustable, metal shelving commonly used in libraries and archives: cantilever, case-style, and industrial. Cantilever shelving (fig. 1) is widely used in libraries because it is strong and easily adjusted. tabs inserted into slots on the uprights support the weight of the shelf. In L & T or case-style shelving (fig. 2), the shelf is supported along its entire length by two metal bars with tabs that are inserted into the sides of the case. It is not as easily adjustable, but is extremely strong. Unlike cantilever shelving that is generally open above the top shelf, L & T shelving has a canopy top, which is useful for securing the full-length dividers needed for sound recording disc collections. Industrial shelving (fig. 3) comes in many varieties. Typically, the shelves are attached to the frame with nuts and bolts or sometimes with clips. Since it requires tools to reset the shelf heights, it is the least easily adjusted. However, it is quite strong and inexpensive compared to other types of shelving. In general, it is not suitable for storage of library collections as the nuts and bolts intrude into the shelf area where the materials are housed. This and other features of the shelving may damage the collection materials.

**Figure 1 Cantilever Shelving**  
**Stanford University Music Library**



**Figure 2 L & T Shelving**  
National Audiovisual Conservation Center  
(NAVCC)

Most sound recording formats need to be shelved upright, and shelf dividers are frequently required to hold discs and tapes perpendicular to the shelf without falling or sliding. Book ends or spring-loaded shelf supports do not



**Figure 3 Industrial Shelving**  
Stanford University Music Library

provide the stability needed for most sound recordings.

Full-length dividers are needed and commonly require slotted shelving into which the tabs of the dividers are inserted (fig. 4). The slots should be spaced at one-inch intervals to accommodate different amounts of materials on the shelves. The dividers are typically used to hold disc collections upright without leaning. The tabs of the dividers should not protrude into the bottoms of the shelves above as this could damage the discs on the upper shelf. If at all possible, the archive should acquire slotted shelving for the entire collection even if it is used for other materials. This way as the needs of the collection change, materials can be easily shifted from one section to another and there will always be a sufficient number of slotted shelves. Also, the support of dividers are also helpful for reel-to-reel tapes and other materials.



**Figure 4 Full-length Shelf Dividers**  
NAVCC

The thickness gauge of the metal shelves needs to be matched to the weight of the materials that the shelves will hold. Several sound recording formats require significantly stronger shelving than that needed for standard library books. For this reason, the load-bearing capacity of the shelving or cabinets and floor holding the sound recordings will need to be much stronger than is typical for standard building construction. In addition, shelving for shellac, vinyl, and lacquer discs need to be reinforced to keep the center of the shelf

from bending or bowing, because the discs

are heavier than most library materials and the weight is focused on the very center of the shelf. If it is at all possible, shelving should be acquired that is strong enough to hold the heaviest materials in the collection. This way, as the needs of the collection change, materials can be shifted from one section to another without the fear that the shelving could collapse under the weight of heavier materials.

Wooden shelving is not recommended for sound recording collections because many formats are too heavy to be supported by such a material, which will bend under the weight of the recordings. Also, wooden shelving tends to be more expensive.

Regardless of what type of shelving is selected, the surfaces that come in contact with the library materials should not have any protruding materials (hardware and other fasteners) that will damage the materials or gaps where thinner objects, such as discs, can fall down or become lodged in cracks. If bolts or other fasteners are used, they should be recessed so as not to contact the materials. Shelving for sound recordings should also include a backstop on the shelves or a back panel to keep materials securely positioned.

### 3.2.2 Compact Shelving

Compact shelving is ideal for many archival applications as it maximizes the use of the available building space by minimizing the need for extra aisle space. Also, since the stack area is accessible only to staff, the need for browsing or entry into several aisles at the same time is reduced. In earthquake prone areas, compact shelving helps to prevent materials from coming off of the shelves, providing greater protection for collections in these regions. Because of its great shelving density, the use of compact shelving requires even greater floor loading capacity. This in combination with the higher than average weight of many sound recording formats can add significant cost to building construction for a sound archives and is a major consideration in housing any sound archive collection.

### 3.2.3 Shelving Sizes

A typical shelving section uses three-foot long shelves. Two or 2 ½ foot long shelves may be used in combination with three-foot shelves to accommodate the size of the room. Shelving sections shorter than two feet are not space efficient, because the uprights holding the shelves use up about one inch of shelf space. This also means that the typical shelf has a capacity of about 35 inches rather than 36 inches. A three-foot shelf is the longest shelf length that is strong enough to hold most sound recording formats. Therefore, shelves longer than three feet are not recommended.

In most sound archives, materials are predominantly 7, 10, and 12 inches, as in the case of sound discs and tapes. The shelf depths should be at least 1 inch more than the material to be shelved. This is especially important when employing compact shelving, because any material extending past the end of the shelf could be damaged. Shelving manufacturers refer to the nominal depth of the shelving, which can be as much as an inch greater than the actual shelf depth to take into account the space in the back required for the uprights that support the shelves. Thus, a nominal twelve-inch shelf may be only 11 inches deep.

The distance between shelves should be set to allow 1-2 inches above the material to be shelved. The height of the shelving upright, and therefore, the number of shelves per shelving



upright will be dependent upon the available ceiling height. The Library of Congress has a quarter-inch lip on the front of all of their shelves for recordings to insure that the items do not



**Figure 5 Shelf with ¼-inch Lip**  
NAVCC

inadvertently fall from the shelves when items are pulled or other activities. If shelving lips are used, the clearance will also need to allow for the height of the lip (fig. 5).

### 3.3 Cabinets

Cabinets are useful for materials that are not easily stored on shelves due to their shape small size, and/or fragility (e.g., cylinders). Cabinets also allow the materials to be easily shifted just as with shelving. They provide ideal protection for materials in areas prone to earthquakes. Small items in plastic cases such as audiocassettes and compact discs can

slide off of shelves easily. Since these materials are only two to five inches wide, the shelves to accommodate them will be very small in comparison to the necessary aisle space between the shelves, making cabinets a more space efficient solution for these materials.

Metal cabinets are preferred again because of their durability and cost. The cabinets can be made in three-foot widths to match the width of shelving units. Drawer depths are generally no more than eighteen inches. Drawer heights should allow ½ to 1-inch clearance between the top of the material and the bottom of the drawer above. The top drawer should be no higher than about forty-two inches or waist height, as it becomes more difficult to see the materials in cabinets that are too high.

Dividers at adjustable distances within the drawers can help keep the materials in order especially in cases where the drawers are not full. If the drawers are full or close to full, dividers may not be necessary as the materials cannot shift around in the drawers in this case. Supports can be used to keep materials from moving within the divided sections when not full. To use the space above the cabinets, a cabinet with vertical drawers can be stacked on top of the horizontal cabinets. The vertical drawers must have shelves within the drawers matching the size of the materials (fig. 6).

Where cabinets are used, wide aisles will be necessary to accommodate the opening of the drawers and a user—typically 5-6 feet. Compared to shelving, lower storage capacity per square foot may result when using cabinets because of the need for extra aisle space.



**Figure 6 Horizontal Cabinet with Vertical Cabinet on Top**  
NAVCC

This will depend on the height of the shelving used and whether it is stationary or compact shelving.

### **3.4 Boxes on Shelves**

Boxes are typically used to house and identify special archival collections. Archival acid-free boxes are available to fit nearly every standard sized audio object. Boxes can also be used in combination with shelving in lieu of cabinets for materials that are too small to fit efficiently on shelves or too fragile. For example, cassettes can be placed in a twelve-inch long box that can then use the entire depth of a thirteen-inch deep shelf that can also accommodate LP discs. This provides flexibility for how the shelving is used as the needs of the archive or library change over time, compared to cabinets, which are more specific to the sizes and types of materials that they house. Boxes are not a good solution for materials where interfiling or frequent shifting is necessary.

## **4. Floor Loading Capacity**

Older sound recording formats are much heavier than materials in typical library or archival collections. Consequently, the shelving needed to hold these materials must be made of stronger and heavier materials also. The appendix provides approximate weights per linear foot for the recording formats found in most sound archives. The shelving, furnishings, archive materials themselves must all be taken into account when determining the floor load for a collection. In most buildings only the ground floor can accommodate sound recording archives. Upper floors usually need to be specially constructed to withstand these heavier loads, meaning that it is usually not possible to repurpose the upper floors of an existing building as a sound archive without costly reinforcement of the floors. The weight of 12-inch 78-rpm shellac records can be as much as 225 lbs. on a three-foot shelf for the recordings alone.

## **5. Storage Arrangements**

Consideration needs to be given to the order in which the materials will be arranged, as this will affect options for how the recordings can be stored. Most studies of this issue compare classification systems (as with library books), accession numbers, or recording manufacturer's name and number. Despite the number of studies of this issue, there has never been a classification system for recordings that has been widely adopted in practice to the degree that it has for books. Also, since sound archives do not need to be concerned with direct public accessibility and browsing of recordings, the need for a classified system is much lower.

Accession numbering is a practical and easy solution allowing the shelves or cabinets to be filled uniformly and without the need for shifting to add new items into the existing collection. It also requires good bibliographic control in order to locate the recordings, as there is no other logic to the arrangement other than the order in which the recordings are acquired.

The use of the manufacturer's label name and number is frequently used in many sound archives. This system requires the ability to shift recordings as new discs are acquired. The numbering schemes are far from standardized, requiring good documentation of sorting and filing rules for the different recording labels. However, this arrangement has several advantages. The numbers are relatively unique for each recording and are printed or etched on the recording

itself. As a basic inventory system, it allows the archive to be able to locate a recording easily before and after the discs are cataloged. When dealing with large numbers of recordings, it is easier to determine when duplicate recordings are acquired and to be able to compare the physical condition of similar discs, thus allowing the archive to quickly determine whether or not to retain duplicate recordings.<sup>5</sup>

## 6. Sound Recording Formats

Different recording formats have specific storage needs due to their differing sizes, weights, and composition. In this section the shelving requirements of each format are outlined. Standard sizes and approximate weights are given in the appendix.

### 6.1 Cylinders

#### 6.1.1 Storage recommendations

6.1.1.1 Material type: Standard size cylinders, 2 and 4 minutes, 2 1/8 in. diameter x 4 1/4 in. length

Storage container: Polyethylene container, 2 9/16 in. diameter x 5 in. length

Alternatively: Acid-free cardboard box with polyethylene foam interior post, 5 x 3 x 3 in.

Storage method: Metal cabinet with drawers

Drawer dimensions (interior): 4 x 32 5/16 x 15 1/2 inches, with 2 inches of clearance between the top of the items and the bottom of the drawer above, adjustable dividers optional

Capacity: ca. 70 cylinders per drawer (polyethylene container); 50 cylinders per drawer (acid-free box)



Figure 7 Cylinder Cabinet  
NAVCC

<sup>5</sup> A discussion of different methods of arranging sound recording discs and the related literature is given in Robert Michael Fling, *Shelving Capacity in the Music Library*, MLA Technical Reports, no. 7 (Philadelphia: Music Library Association, 1981): 23-24; a more recent study coming to basically the same conclusions is Linda Crow, "Shelf Arrangement Systems for Sound Recordings: Survey of American Academic Music Libraries," *Technical Services Quarterly* 8, no. 4 (1991): 1-24.

6.1.1.2 Material type: Cylinders, 2 1/8 in. diameter x 6 1/8 in. length

Storage container: Acid-free cardboard box with polyethylene foam interior post, 7 x 3 x 3 in.

Storage method: Metal cabinet with drawers

Drawer dimensions (interior): 4 x 32 5/16 x 15 1/2 inches, with 2 inches of clearance between the top of the items and the bottom of the drawer above, adjustable dividers optional

Capacity: 50 cylinders per drawer (acid-free box); polyethylene not available at the time of this report



Figure 8 Cylinder Cabinet (6-inch Cylinders)  
NAVCC

6.1.1.3 Material type: Grand Concert Cylinders

Storage container: Custom made acid-free cardboard box with interior post

Storage method: Metal cabinet with drawers

Drawer dimensions (interior): 4 x 32 5/16 x 15 1/2 inches, with 2 inches of clearance between the top of the items and the bottom of the drawer above, adjustable dividers optional

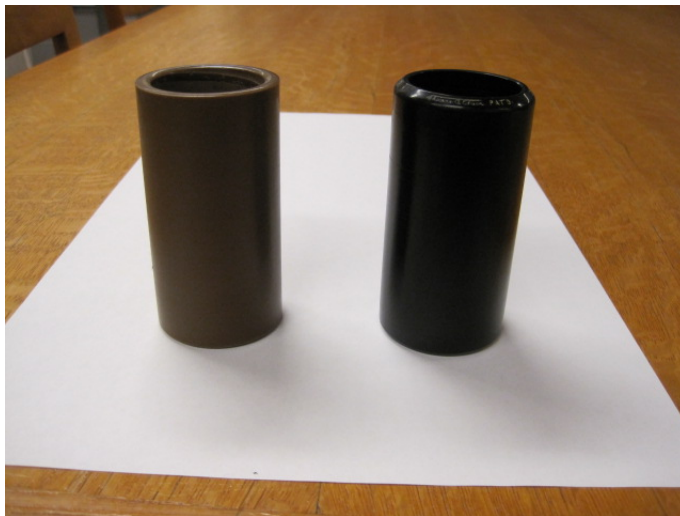
Capacity: 8 cylinders per drawer



Figure 9 Cylinder Cabinet (Grand Concert Cylinders)  
NAVCC

### 6.1.2 Physical aspects

Cylinder sound recordings date from 1889 to 1929, the earliest days of recording through the end of Thomas Edison's recording company, with the minor exception of some business dictation cylinders, which were produced as late as the 1960s.<sup>6</sup> Cylinders were made of either wax or celluloid. Wax cylinders come in three basic types: white (which are quite rare), brown,



and black. White and brown wax cylinders are the earliest and are a quite soft material. Because they are composed almost entirely of organic compounds, they are susceptible to mold damage under adverse environmental conditions. Black wax cylinders are not as soft as the brown wax cylinders, but are quite brittle. They are also susceptible to mold damage, but such damage is generally not as extensive as with brown wax cylinders stored under the same conditions. All wax cylinders are highly fragile and easily broken if dropped or mishandled. Fig. 10.

Figure 10 Wax Cylinders  
Stanford Archive of Recorded Sound

<sup>6</sup> Peter Shambarger, "Cylinder Records: An Overview," *ARSC Journal* 26, no. 2 (Fall 1995): 156-161.





**Figure 11 Celluloid Cylinders**  
Stanford Archive of Recorded Sound

causing the celluloid to shrink. Also, the core materials may expand, especially in conditions of high humidity. A stable environment is critical to preserving celluloid cylinders.

Celluloid cylinders (fig. 11) are more durable than wax cylinders and not as easily damaged by mold. However, they should still be handled carefully. Celluloid is a compound made from nitrocellulose and camphor and is flammable. Therefore, exposure to high temperatures should be avoided. Celluloid cylinders are formed around a core material. Different companies employed different materials for the core including plaster, plaster of Paris, cardboard with metal end rings, and a resin coated wood pulp material. These cylinders are susceptible to splitting, as the camphor tends to leech out with aging

### 6.1.3 Storage Details

Cylinders should be stored vertically on end in individual boxes in cabinets. If stored horizontally, the weight of the cylinder over time could cause it to deform, resulting in the playing surface no longer being perfectly round, effecting playback and positioning onto the mandrel of the cylinder player. Cylinders were originally sold in cardboard boxes into which the cylinders slid with a paper lid on one end. Because the playing surface is delicate and needs protection, many of these boxes were lined with a cotton felt-like fabric to eliminate abrasion against the cardboard surface of the box. Unfortunately, the cotton lining attracts moisture and causes mold under conditions of high humidity and temperature. Consequently, it is advisable to store cylinders in boxes other than the originals (fig. 12).



**Figure 12 Original Felt-Lined Cylinder Boxes**  
Stanford Archive of Recorded Sound

Two boxes have been developed for individual cylinder storage. The cylinder needs to be held securely so as to not move around within the box, with no contact on the playing surface, which is easily damaged by abrasion. The surface also needs to be open to the air and free from contact with materials that could cause mold growth. The Hollinger Metal Edge Company created a three-inch square box of acid-free board with a foam cushion on the top and bottom holding the ends of the cylinder in place and a center foam spindle 2 ¼ inches in length by 1 ½ inches in diameter. A separate lid allows access to the box. The box holds the cylinder in place and allows air circulation around the playing surface (fig. 13). The Association for Recorded

Sound Collection's (ARSC) Technical Committee has been working on a different design for a cylinder box. A prototype was made in 2007, and the first boxes were produced in 2012. This box is cylindrical and its external dimensions are a little less than 5 inches in length by 2 9/16 inches in diameter for a standard size cylinder. This box is molded from inert plastic materials with a top and bottom silicone foam cushion. The inner post runs the entire length of the cylinder for complete support. The cylinder lid has a twist lock feature to hold the item in place while still allowing for easy access. The design keeps the playing surface completely free from contact with the box and the inner spindle guides the cylinder in place so that there is no abrasion of the playing surface (fig. 14).

Cabinets provide the best protection with the advantage of easy access to each individual cylinder, little chance of dropping the cylinders, and good protection in the case of earthquakes. The cabinets should only be 3-4 feet high as there is a danger of dropping the cylinders stored in higher cabinets or shelves.



Figure 13 Hollinger/Metal Edge Cylinder Box  
Stanford Archive of Recorded Sound



Figure 14a ARSC Designed Cylinder Box  
NAVCC



Figure 14b ARSC Designed Cylinder Box  
NAVCC

Another approach is to place the cylinder boxes within another acid-free box that is then stored on standard shelving. The cylinders should not be placed on shelves requiring a step stool or ladder to minimize the possibility of

dropping a box. The boxes should be placed on shelves up 4-5 feet high only, with other materials on the upper shelves, because of the danger of dropping boxes stored at higher levels.



This alternative should only be used where cabinets are not a possibility. Due to the fragility of cylinders, cabinets are preferred.

#### 6.1.4 Arrangement

Cylinders can be arranged by manufacturer name and number within cabinets but this may require frequent shifting. Keeping the drawers full will stop the cylinders from moving when drawers are opened, and avoiding breakage. Accessioning the cylinders is probably the best solution to avoid excessive handling and should certainly be the method of choice when a collection is boxed rather than stored in cabinets.

### 6.2 Discs

#### 6.2.1 Shellac Discs

##### 6.2.1.1 Storage Recommendations

Shellac discs can be stored directly on shelves. All shellac discs regardless of size should use shelves of the same type described here.

Storage method: Metal L & T type shelving, single or double-face units generally 3 feet wide, with shelves 3 feet wide and including backstops or a back panel.

Shelving features: Dividers extending the full height and depth of the shelf that are adjustable at one inch increments and placed every 6 inches when the shelf is filled to capacity (6 dividers per shelf); all shelving surfaces should be smooth with no hardware coming in contact with the discs; backstop for each shelf or a back panel for the shelving unit.

##### 6.2.1.1.1 Material type: 7 inch shellac

Storage container: Acid-free sleeves open at the top end with 3-inch center hole and a Mylar outer sleeve open on the back end.

Shelf depth: 8 inches (actual)

Shelf height: 8-9 inches between shelves

Total capacity: ca. 360 single discs per three-foot shelf

Load bearing capacity: at least 20 lbs. per linear foot or ca. 60 lbs. per three-foot shelf

##### 6.2.1.1.2 Material type: 10 inch shellac

Storage container: Acid-free sleeves open at the top end with 3-inch center hole and a Mylar outer sleeve open on the back end.

Shelf depth: 12 inches (actual)

Shelf height: 12 inches between shelves

Total capacity: ca. 330 single discs per three-foot shelf

Load bearing capacity: at least 52 lbs. per linear foot or ca 155 lbs. per three-foot shelf

#### 6.2.1.1.3 Material type: 12-inch shellac

Storage container: Acid-free sleeves open at the top end with 3-inch center hole and a Mylar outer sleeve open on the back end.

Shelf depth: 14 inches (actual)

Shelf height: 13-14 inches between shelves

Total capacity: ca. 295 single discs per three-foot shelf

Load bearing capacity: at least 74 lbs. per linear foot or ca. 220 lbs. per single three-foot shelf

#### 6.2.1.2 Physical Characteristics

Emile Berliner, the inventor of the first disc recording, began manufacturing discs composed of hard rubber. By 1895, the discs were made of shellac. This remained the primary material in disc sound recordings through the 1950s with the advent of the long playing (LP) disc recording, although there was a significant amount of variation of other elements combined with the shellac.<sup>7</sup> In general, shellac discs present a hard surface and are relatively inflexible. The records become more brittle with age, which is observable in archival collections and through artificial aging tests. This means that shellac discs are more susceptible to breakage with age. Shellac discs will warp over time if steady pressure or weight is applied to them, but they are much less susceptible to warpage than vinyl discs especially as they age. The inflexibility and brittleness of the records is a major consideration in how the discs are shelved and stored.<sup>8</sup>

The size of shellac discs was standardized fairly early to either ten or twelve inches in diameter (fig. 15), although several recording companies produced a fair number of discs that are 7 (e.g., Berliner), 10 ½ (e.g., Odeon and Fonotipia), 11 ½, and 14 inches (e.g., Pathé). Shellac discs larger than 14 inches are fairly rare.



**Figure 15 Ten- and Twelve-Inch Shellac Discs**  
Stanford Archive of Recorded Sound

The weight of shellac discs is a serious consideration for storage and housing. The number of 10 and 12-inch shellac discs per linear foot varies due to slight differences in the thickness of the discs produced by different companies at different times and due to the differences in the paper sleeves containing them. For practical purposes, approximately 100 discs per linear foot should be used for determining shelf capacity and weight.<sup>9</sup> As with the thickness of the discs, the weight of

<sup>7</sup> A full explanation of the composition of disc recordings is outside the scope of this paper. For more information on the materials used for shellac recordings and the effects of storage and aging of shellac see, Pickett and Lemcoe, p. 24-26.

<sup>8</sup> Pickett and Lemcoe, p. 25.

<sup>9</sup> Richard Warren provides much lower numbers in his study, see Warren, p. 136. The data in this study was obtained by measuring several stacks of discs from different recording companies and taking the average. The discs were measured by placing them flat on a table in a stack. The effect of gravity allowed for greater consistency than measuring a linear foot of discs shelved vertically. Discs should not be stored on shelves or in boxes at this density, because it would be difficult to pull the records from the shelf. However, these item counts and weights represent the maximum amounts possible per linear foot and are useful to insure that the shelving and floors are strong enough for

each item also varies. When planning for the load bearing capacity of floors and shelving, a weight of 80-90 lbs. per linear foot is advised.

The discs were originally distributed either as single discs or in album sets. The traditional album sets consist of cardboard covers with interior paper sleeves for each disc that look much like early photograph or scrapbook albums. Many record collectors placed their single discs in these albums, which they purchased for home storage. While the albums proved convenient for storing the records on shelves much like books, their construction frequently caused the discs to break when placed flat on a table, opened, and the “pages” of the album turned. When this is done, the discs slip to the center of the album and catch in the spine of the album. If the handler is not careful, the edge of the disc can snap or break as the page is turned. When opening such an album, it should be placed vertically rather than horizontally on a table surface to remove the discs so that they do not gravitate to the center of the album. Consequently, the discs in an album should be removed and stored in individual sleeves with the albums stored separately (fig. 16).



Figure 16 Shellac Disc Albums  
Stanford Archive of Recorded Sound

### 6.2.1.3 Shelf Arrangement

The use of the manufacturer’s label name and number is frequently used in many sound archives. This system requires the ability to shift recordings as new discs are acquired, and the numbering schemes are far from standardized, requiring good documentation of sorting and filing rules for the different recording labels. However, this arrangement has several advantages. First, the numbers are relatively unique for each recording and are printed or etched on the recording itself. As a basic inventory system, it allows the archive to be able to locate a recording easily before and after the discs are cataloged. When dealing with large numbers of recordings, it is easier to determine when duplicates are acquired and to be able to compare the physical condition of similar discs, thus allowing the archive to quickly determine whether or not to retain duplicate recordings.<sup>10</sup>

Accession numbering is a practical and easy solution allowing the shelves to be filled uniformly and without the need for shifting to add new items into the existing collection. It also

the collection. The numbers and weights of the discs given in the appendix are approximate due to the inherent variations in manufacturing over time.

<sup>10</sup> A discussion of different methods of arranging sound recording discs and the related literature is given in Robert Michael Fling, *Shelving Capacity in the Music Library*, MLA Technical Reports, no. 7 (Philadelphia: Music Library Association, 1981): 23-24; a more recent study coming to basically the same conclusions is Linda Crow, “Shelf Arrangement Systems for Sound Recordings: Survey of American Academic Music Libraries,” *Technical Services Quarterly* 8, no. 4 (1991): 1-24.

requires good bibliographic control in order to locate the recordings, as there is no other logic to the arrangement other than the order in which the recordings are acquired.

#### 6.2.1.4 Storage Details

For shellac discs, acid-free paper sleeves are the best solution for long-term storage. For easy access to the printed information, a center hole can be cut in the sleeves. To prevent dust contamination, this acid-free paper sleeve is placed in a Mylar jacket with the opening of the paper sleeve at the top. This prevents any dust from entering the sleeve. A sleeve without a center hole and a top flap totally enclosing the disc could be used. However, a top flap may introduce imprinting problems, resulting in damage to the recording. Keeping the environment dust-free through the use of HVAC filters and regular cleaning is equally important.

Disc recordings should be stored vertically as close to perpendicular to the shelf as possible rather than horizontally. The Pickett and Lemcoe study conducted thorough experiments on the effects of gravity and stresses on discs caused by stacking. Discs that are stored horizontally can experience imprinting on the playing surface from sleeves and packaging materials that are not perfectly flat, such as the overlap of seams in a record sleeve. Imprinting on the grooves of the recording will play back as audible pops and clicks or prevent the stylus from tracking properly in the groove. Shelving records vertically but not fully perpendicular to the shelf can cause warpage over time.<sup>11</sup>

Since discs that lean against the shelf ends or against one another can develop warpage over time, shelving for shellac discs should be constructed with dividers placed no more than six inches apart. The dividers should be perfectly flat and extend the entire depth and height of the shelf to provide support for the weight of the disc to avoid imprinting on the recordings. The dividers should be adjustable so that if there are fewer than six inches of discs, the dividers can be moved closer together to keep the discs upright. Discs should be fully packed between the dividers so as to be easily removed without exerting undue pressure on the surrounding discs and



Figure 17 Dividers for Discs  
NAVCC

still remain at a 90-degree angle to the shelf (fig. 17). The Library of Congress recommends leaving a space in each divided section of about the width of one finger. Spring-loaded shelf-ends are not recommended as the pressure of the spring against the recordings could result in imprinting over time.

In addition, only like sized materials should be stored together to avoid problems of imprinting and warpage. That is, ten-inch discs in single sleeves should only be stored with other ten-inch discs in single sleeves. Mixing ten, twelve, and other size discs together on the same shelf or in the same box introduces mechanical stresses that can lead to warpage and imprinting of the playing surface when

<sup>11</sup> Pickett and Lemcoe, 42, 45-46, 49, 51.

stored over long periods of time simply from the weight of gravity or the pressure of the discs against one another. For these reasons and because of the increased risk of breakage in handling, the cardboard albums found with some shellac recordings should also be removed and stored separately from the discs.

When shellac discs are part of an archival collection, the discs should be placed in sleeves and then inserted in a box six inches deep, and conforming to the size of the disc, either 10  $\frac{3}{4}$  x 10  $\frac{3}{4}$  for ten-inch discs or 13 x 13 inches for twelve-inch discs. The box should be filled fully but allow the discs to be removed from the box easily without undue pressure on the other discs. If there are not enough discs to fill the box, an acid-free cardboard spacer covering the entire height and width of the box should be used. Fig. 18.

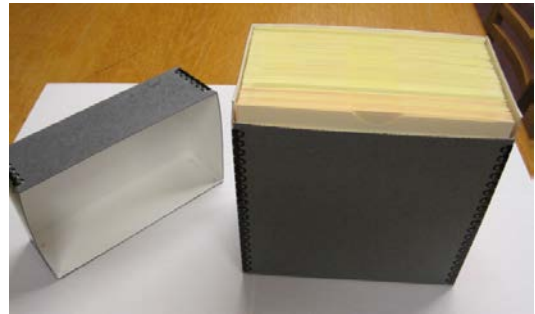


Figure 18 Box for Shellac Discs  
Stanford Archive of Recorded Sound

Shelving with dividers is needed in collections of discs arranged by classification or manufacturer's number, because discs will continue to be added at various points in the collection and will necessitate shifting as the shelves fill. If the recordings are shelved by accession number, the order of the recordings is fixed and newly acquired discs are added on to the end of the sequence. In this arrangement, the discs can be placed in acid-free sleeves and then in acid-free boxes. The boxes can then be placed on standard, undivided shelving. The cost of the shelving is much less and is only offset slightly by the cost of the acid-free boxes. Since the records are only added at the end of the numerical sequence, the shelves can be filled to 100 percent capacity saving space, and staff costs for shifting are eliminated as well. The archive will need to weigh these cost savings against the benefits and operational needs of adopting the classification or manufacturer's number arrangements.

The standardized size of recorded discs means that, unlike books, shelving can be set for seven, ten, and twelve inches discs for the vast majority of a record collection leaving at least 1-2 inches of clearance between the top of the discs and the shelf above. Unless an archive has a large number of discs in sizes other than ten and twelve inches, the shelves set for ten and twelve inch discs can be used for other sizes without significant loss of shelving space.

### 6.2.2 Vinyl and Plastic Discs

Vinyl and plastic discs can be stored directly on shelves. These discs regardless of size should use shelves of the same type described here.

Storage method: Metal cantilever or L & T type shelving, single or double-face units generally 3 feet wide, with shelves 3 feet wide and including backstops or a back panel. Shelving features: Dividers extending the full height and depth of the shelf that are adjustable at one inch increments and placed every 6 inches when the shelf is filled to capacity (6 dividers per shelf); all shelving surfaces should be smooth with no hardware coming in contact with the discs; backstop for each shelf or a back panel for the shelving unit.

### 6.2.2.1 Storage Recommendations

#### 6.2.2.1.1 Material type: 7-inch vinyl

Storage container: Original cardboard jackets or boxes with the individual discs in a static-free polyethylene sleeve

Shelf depth: 8 inches (actual)

Shelf height: 8-9 inches between shelves

Total capacity: ca. 365 single discs per three-foot shelf

Load bearing capacity: at least 12 lbs. per linear foot or ca. 35 lbs. per three-foot shelf

#### 6.2.2.1.2 Material type: 10-inch vinyl

Storage container: Original cardboard jackets or boxes with the individual discs in a static-free polyethylene sleeve

Shelf depth: 12 inches (actual)

Shelf height: 11-12 inches between shelves

Total capacity: ca. 220 single discs per three-foot shelf

Load bearing capacity: at least 37 lbs. per linear foot or ca. 110 lbs. per single faced unit

#### 6.2.2.1.3 Material type: 12-inch vinyl

Storage container: Original cardboard jackets or boxes with the individual discs in a static-free polyethylene sleeve

Shelf depth: 14 inches (actual)<sup>12</sup>

Shelf height: 14 inches between shelves

Total capacity: ca. 260 single discs per three-foot shelf

Load bearing capacity: at least 48 lbs. per linear foot or ca. 145 lbs. per single faced unit<sup>13</sup>

#### 6.2.2.1.4 Material type: 16-inch vinyl

See 6.4 Lacquer Discs

### 6.2.2.2 Physical Characteristics

Various types of plastics have been used for sound recording discs. Plastic discs were introduced as early as 1931 by RCA Victor but did not become common until after World War II with vinyl becoming the predominant material. Polyvinyl chloride (PVC) is the primary component in vinyl. Vinyl is softer, more pliable, and flexible than shellac. The softer surface

<sup>12</sup> The fourteen-inch depth and height here allows for the shelving of LP box sets along with single LP albums. Some of these box sets measure as much as fourteen inches deep and over thirteen inches high. Some archives may want to set up an oversize section for these box sets and set the majority of the shelves at 13-14 inches for the rest of the discs if space does not allow setting all of the shelves at 14 inches.

<sup>13</sup> Fling discusses techniques for libraries and archives to determine the ratio of single LP discs to box sets and provides a chart giving the number of discs for different ratios. This is useful for determining the number of linear feet needed to house an LP collection. However, archives should plan the load bearing capacity of floors and shelving on single LP albums only, as there may be shelves in the collection composed primarily or entirely of single discs. Fling, 26-29



results in less surface noise, although it is more easily scratched and worn by playback. Its flexibility makes the record less easily broken when dropped than shellac records. Vinyl discs were found to be quite chemically stable in accelerated aging tests, proving to have a useful life of one hundred years or more under normal environmental conditions.<sup>14</sup> However, their flexibility and softness makes them more susceptible to warpage and imprinting than shellac records.

Some vinyl discs were produced during the 78 rpm era, but the introduction of vinyl records roughly corresponded to the beginning of the production of 45 rpm and long-playing records (LPs at 33 1/3 rpm) capable of longer playing times. Three standard sizes of discs correspond to the same sizes for 78rpm discs: 7, 10, and 12 inches. The seven-inch, 45-rpm disc was introduced by RCA Victor in 1949 and eventually was used primarily for popular music. It is easily distinguished by the large spindle hole in the center. The 45-rpm discs were first made of vinyl and later of polystyrene (fig. 19).<sup>15</sup> Columbia introduced the modern, twelve-inch LP record in 1948 (fig.20).<sup>16</sup> Ten-inch discs were also made in vinyl, but the other two sizes predominate.



Figure 19 45 rpm Disc with Acid-Free Paper Sleeve  
Stanford Archive of Recorded Sound

Ten and twelve-inch records were generally packaged in cardboard jackets open on one end with the record contained inside a paper or plastic inner sleeve also open on one end. When



Figure 20 Twelve-Inch Vinyl Disc with Jacket and Anti-Static Inner Sleeve  
Stanford Archive of Recorded Sound

new, the records were distributed in the jackets covered by a plastic shrink-wrap. The seven-inch 45-rpm records could be packaged in the same way, but were frequently distributed with only a paper sleeve, similar to the LP inner sleeve, with a cutout center hole to make the label visible. Double record sets were sometimes distributed in a folded cardboard jacket with the individual records in paper sleeves. For larger album sets, the records were placed in inner sleeves that fit into a 12 x 12 inch box. Sometimes LP records were issued with additional program notes, lyrics, and/or advertising material printed on 12 x 12 inch sheets inserted into the jacket or

<sup>14</sup> Pickett and Lemcoe, 28-31, 41.

<sup>15</sup> *Encyclopedia of Recorded Sound*, 2<sup>nd</sup> ed. (New York : Routledge, 2005), s.v. "45-rpm Discs."

<sup>16</sup> *Encyclopedia of Recorded Sound*, 2<sup>nd</sup> ed., s.v. "Long-Playing Record."



album box.

Vinyl discs are not as heavy as shellac discs, but are generally heavier than books, and thus require special considerations in a library and archival setting.<sup>17</sup> The number of 12-inch LP discs per linear foot varies due to differences in the thickness of the discs produced by different companies at different times and particularly due to the differences in the cardboard jackets containing them. Box sets of LPs can vary considerably depending upon how they are packaged. The variation is frequently caused by program booklets that take up considerable space in the boxes and do not weigh as much as discs.<sup>18</sup> When planning for the load bearing capacity for floors and shelving, a maximum weight of about 48 lbs. per linear foot is advised.

#### 6.2.2.3 Shelf Arrangement

The methods of shelf arrangement for LPs are identical to those described for shellac discs.

#### 6.2.2.4 Storage Details

Unlike shellac discs, it is common practice to shelve LPs in the original cardboard jacket or box despite the acid content of the paper. The cardboard jackets and boxes frequently contain cover art and program notes that the archive wants to associate with the recording and needs to preserve. Also, vinyl discs frequently acquire a static charge that attracts dust and particles to the playing surface that can be heard in playback. The disc can be protected from the packaging materials by replacing the inner paper or PVC sleeve with an inert, static-free polyethylene sleeve. Acid-free paper inner sleeves could be used, but the static charge of the discs may attract small paper fibers from the sleeves. Also, the thin polyethylene sleeves fit well into the original record jackets, which do not allow much room except for the disc itself. The inner sleeve should be rounded on one end so that the sleeve corners do not fold over inside the jacket as this could cause imprinting. Inserting the sleeve so that the opening is at the top of the jacket will seal the record inside and prevent dust from getting on the disc. Also, it is important to insert the sleeve into the jacket without the top corner folding over and being a source of imprinting.

As with shellac discs, vinyl disc recordings should be stored vertically as close to perpendicular to the shelf as possible rather than horizontally. This is even more important with vinyl discs because they are more prone to warpage and imprinting than shellac discs. Studies show that shelving records vertically but with even a ten degree lean from fully perpendicular to the shelf can cause warpage over time affecting playback.<sup>19</sup> The same type of shelving with dividers as used for shellac recordings is recommended for LPs, and only like sized materials should be stored together, i.e., seven, ten, and twelve-inch discs should be segregated by size.

Vinyl discs that are part of an archival collection may be inserted in an acid-free box six inches deep and conforming to the size of the disc, either 10 <sup>3</sup>/<sub>4</sub> x 10 <sup>3</sup>/<sub>4</sub> for ten-inch discs or 13 x

<sup>17</sup> Richard Warren calculates 66 discs at 34 lbs. per linear foot for 12-inch vinyl discs. Richard Warren, 136. This corresponds roughly to the number of single LPs per linear foot as measured by Fling, who determined the measurement to be 63 discs per linear foot; Fling, 27. These figures must take into account a mixture of single albums and box sets. The appendix gives estimates for single albums and box sets separately.

<sup>18</sup> See footnote 12.

<sup>19</sup> Pickett and Lemcoe, 35.

13 inches for twelve-inch discs. As with shellac discs, the box should be filled fully but still allow the discs to be removed easily without undue pressure on the other discs. If there are not enough discs to fill the box, a cardboard spacer covering the entire height and width of the box should be used.

Seven inch 45 rpm discs with cardboard jackets or in boxes can be housed the same way as ten and twelve inch LPs. Discs without jackets can be placed in an acid-free paper sleeve with the center hole cut out to make the label information visible. If dust and static attraction are a concern, a polyethylene inner sleeve can be used with the acid-free paper sleeve.

As with shellac discs the standardized sizes allow shelving to be set for seven, ten, and twelve inch discs leaving at least 1-2 inches of clearance between the top of the discs and the shelf above. Almost every collection will also need an area for recordings that come with oversize or non-standard packaging. In these cases, judgment will be needed to determine the most effective way to house the material. In some cases it may be preferable to separate the discs from the packaging and integrate them into the rest of the disc collection with the packaging in a separate location. In other cases, it may be preferable to keep the materials together in the separate location. If the shelves allow for two inches of clearance between the top of the discs and the shelf above, the number of oversize materials can be kept to a minimum. This is preferable as the number of LP box sets exceeding 13 inches is significant. If a classification, accession, or manufacturer number arrangement is used, a blank sleeve in the regular sequence can serve as a useful cross-reference to indicate the presence of the discs in another location.

### 6.2.3 Lacquer Discs

Lacquer discs can be stored directly on shelves. All lacquer discs regardless of size should use shelves of the same type described here.

Storage method: Metal L & T type shelving, single or double-face units generally 3 feet wide, with shelves 3 feet wide and including backstops or a back panel.

Shelving features: Dividers extending the full height and depth of the shelf that are adjustable at one inch increments and placed every 6 inches when the shelf is filled to capacity (6 dividers per shelf); all shelving surfaces should be smooth with no hardware coming in contact with the discs; backstop for each shelf or a back panel for the shelving unit.

#### 6.2.3.1 Storage Recommendations

##### 6.2.3.1.1 Material type: 10-inch lacquer

Storage container: Acid-free sleeves open at the top end with 3-inch center hole and a Mylar outer sleeve open on the back end

Shelf depth: 12 inches (actual)

Shelf height: 11-12 inches between shelves

Total capacity: ca. 160 single discs per three-foot shelf

Load bearing capacity: at least 57 lbs. per linear foot or ca. 170 lbs. per three-foot shelf

#### 6.2.3.1.2 Material type: 12-inch lacquer

Storage container: Acid-free sleeves open at the top end with 3-inch center hole and a Mylar outer sleeve open on the back end

Shelf depth: 14 inches (actual)

Shelf height: 14 inches between shelves

Total capacity: ca. 480 single discs per three-foot shelf

Load bearing capacity: at least 82 lbs. per linear foot or ca. 245 lbs. per three-foot shelf

#### 6.2.3.1.3 Material type: 16-inch lacquer<sup>20</sup>

Storage container: Acid-free sleeves open at the top end with a 5 to 6-inch center hole and a Mylar outer sleeve open on the back end

Shelf depth: 18 inches (actual)

Shelf height: 19 inches between shelves

Total capacity: ca. 400 single discs per three-foot shelf

Load bearing capacity: at least 168 lbs. per linear foot or 500 lbs. per three-foot shelf

#### 6.2.3.2 Physical Characteristics

Lacquer discs, sometimes called acetate discs, were used primarily for instantaneous recordings or home recording from about the 1930s to roughly the early 1950s (fig. 21a), when the advent of magnetic tape recording largely supplanted the use of lacquer discs. Large lacquer discs were frequently used to record radio programs and are sometimes referred to as transcription discs (fig. 21b). Lacquer discs from this time period were manufactured from aluminum discs coated with a layer of nitrocellulose softened with a castor oil plasticizer.<sup>21</sup> During World War II glass was substituted for the aluminum base. These discs are highly fragile in a number of ways. First, the lacquer coating is necessarily soft to allow the surface to be cut



Figure 21a Ten- and Twelve-Inch Lacquer Discs  
Stanford Archive of Recorded Sound



Figure 21b Sixteen-Inch Lacquer Disc  
Stanford Archive of Recorded Sound

<sup>20</sup> Most large lacquer discs are sixteen inches, but there are a considerable number of seventeen-inch and larger discs. A larger shelf depth and height are necessary, and custom boxes and sleeves may be needed.

<sup>21</sup> Pickett and Lemcoe, 15.

easily to make the recording and reduce surface noise. However, this means that the surface is easily chipped or scratched and wears quickly from friction with repeated playing. Secondly, glass based discs are easily cracked or broken if not handled and stored with the greatest care. Lastly, the castor oil plasticizer used in the lacquer oxidizes into palmytic acid over time, which appears as an oily, white coating on the disc that must be cleaned off in order to play the recording. As the disc loses the plasticizer, the lacquer eventually dries, cracks, and may peel off the base, resulting in total failure of the disc (fig. 22). This kind of disc failure has been known to happen in as short as 15 years.<sup>22</sup> However, this behavior is unpredictable as there are lacquer discs over eighty years old that are in playable condition.



**Figure 22 Effects of Palmytic Acid**  
Stanford Archive of Recorded Sound

Lacquer discs were made in the same sizes as shellac and vinyl discs, but the most frequent sizes are 7, 10, 12, and 16 inch discs with the last three sizes predominating. A smaller number of 17 ¼ inch discs and larger also exist. They were distributed in paper sleeves usually with a center hole. Paper labels were glued on to the center of the disc by the user. These labels frequently fall off and may be lost as the glue ages.

Telling the difference between glass and aluminum base discs can sometimes be tricky. If the surface or edge of the disc is chipped exposing the aluminum, the identification is certain. It is also possible to

look at the center holes to see if the disc base is aluminum. However, a number of glass discs were molded with an aluminum center core. It is easy to be fooled that such a glass disc is aluminum. With experience, it is possible to tell the difference by gently tapping the edge of the disc with the fingernail and listening to the sound. For these reasons, it is best to handle all lacquer discs with extreme caution, because they may be made with a glass disc base.

#### 6.2.3.3 Shelf Arrangement

Many collections of lacquer discs are comprised of unique recordings and may be arranged in collections or accessioned. For these collections, boxing the recordings makes for easy identification, but they may also be arranged on shelves without boxing. A manufacturer label and number arrangement is less useful for many of these discs as they were not generally used for mass production and do not have numbers, but such an arrangement may be used if there are.

#### 6.2.3.4 Storage Details

Lacquer discs may be stored in the same way as vinyl discs: an acid-free sleeve with a center hole inserted into a Mylar jacket and placed directly on shelves vertically with as little

<sup>22</sup> Pickett and Lemcoe, 24.

lean as possible, separated by dividers extending the entire depth and height of the shelf, and without mixing sizes of discs on the same shelf.

Lacquer discs should also follow the same storage recommendations for shellac and vinyl discs when stored in boxes six inches wide. Given the fact that lacquer discs can be very heavy and quite fragile with some being made of glass, storage in boxes insures good protection and ease of handling. Especially in the case of sixteen inch discs, the boxes should be no more than three inches wide as the weight of the box could be as much as forty pounds. It is best to use dividers with sixteen inch discs in boxes placed on shelves to insure that the boxes do not lean, tip, or fall. The boxes should always be handled one at a time because of their weight and fragility.

If more than one is moved at a time, a specially designed cart should be used to transport them securely. If a box containing sixteen inch glass discs were to fall, it could crack or break the discs. Many collections of sixteen-inch discs contain lacquer discs with both aluminum and glass bases and also vinyl discs. Storing both lacquer and vinyl discs together poses no problems and actually may be beneficial as the weight of the vinyl discs is less.

The weight of these discs is a serious consideration for storage and handling. The weight of just the discs on a three-foot shelf could reach 500 pounds. Because of their fragility and extreme weight, the 16-inch lacquer discs should be shelved no higher than can be easily reached without the help of a ladder, that is, no more than the fourth shelf high for sixteen-inch discs and the fifth shelf for smaller discs. If boxes are used, sixteen-inch discs should not be more than two shelves high due to the weight of the boxes. In this case, sixteen-inch vinyl discs can be placed on the higher shelves as they are not as heavy and the risk of breakage is much less. There is a risk of dropping a glass disc or a heavy box of discs when retrieving them from shoulder height and above. Using the lower shelves allows for greater ease of handling in general for these fragile materials. Because of the extreme weight of these materials, they should be loaded starting from the bottom shelf to provide greater stability of the shelving unit. Loading them starting at the top, as is customary, could create a top-heavy shelving unit that could tip over.

#### 6.2.4 Compact Discs

##### 6.2.4.1 Storage Recommendations

###### 6.2.4.1.1 Material type: Compact discs

Storage container: Plastic jewel cases

Storage method: Metal cabinet with horizontal drawers up to about waist height with vertical drawers stacked on top

Drawer dimensions (interior): 6 5/16 x 44 1/2 x 22 3/16 inches, allowing 9 rows of CDs per drawer (horizontal drawers), adjustable dividers optional; 26 1/2 x 6 1/4 x 20 1/2 inches allowing 4 rows of CDs per drawer (vertical drawers)

Capacity: based on single CDs in standard jewel case, ca. 500 CDs per horizontal drawer; ca. 200 CDs per vertical drawer

Load bearing capacity: ca. 135 lbs. per horizontal drawer; ca. 55 lbs. per vertical drawer

Alternative storage method: Cantilever or metal L & T type shelving, single or double-face units generally 3 feet wide, with shelves 3 feet by 14 inches (actual); CDs arranged in boxes 6 ¼ x 5 ½ x 12 ¼ inches stacked 2 high per shelf  
 Shelving features: all shelving surfaces should be smooth with no hardware coming in contact with the items; backstop for each shelf or a back panel for the shelving unit.  
 Total capacity: 28 discs per box in standard size jewel cases; 12 boxes per shelf; approximately 336 single discs per three-foot shelf  
 Load bearing capacity: ca. 90 lbs. per three-foot shelf

#### 6.2.4.2 Physical Characteristics

The compact disc (CD) was introduced in 1983 and is composed of an aluminum disc with a plastic playing surface and an opposite label surface covered by lacquer. It is 4 ¾ inches in diameter with a center hole of about 9/16 inches. Most CDs are distributed in a plastic “jewel case,” measuring 4 7/8 x 5 9/16 x 3/8 inches. A thinner jewel case measuring only 3/16 inches is increasingly common.



Figure 23 Thin, Single, and Double CD Jewel Cases  
 Stanford Archive of Recorded Sound

Both cases are capable of holding a small booklet visible through the front of the case. A double jewel case is commonly used for recordings requiring more than one CD and may hold up to four CDs in addition to a small booklet. The double case consists of two outer doors hinged to an inner core and measures 4 7/8 x 5 9/16 x 15/16 inches (fit. 23). Cardboard, paper, and soft plastic cases are sometimes used for CDs, but the jewel case provides superior protection to the playing and label surfaces. The soft plastic cases should not be used as over time the CD label side can stick to the plastic, pulling of the protective lacquer and ruining the disc.

#### 6.2.4.3 Shelf Arrangement

As with shellac discs and LPs, the shelf arrangement can be by manufacturer or accession number. For the former arrangement, cabinets are the most convenient, because it is easy to shift the discs within the drawers. For an accessioned collection, either cabinets or boxes may be used as the disc order is fixed and requires no shifting.

#### 6.2.4.4 Storage Details

CDs may be stored directly on shelves in their jewel cases, but this is not space efficient as the ratio of the shelf depth required for CDs (at only about 6 inches) compared to the necessary aisle space to access the shelves is too great. Consequently, CDs are stored in drawers or boxes. Horizontal cabinets, with drawers to just over waist height on the bottom allow the CDs to be viewed easily. The CDs are shelved with the spines up for easier identification, and dividers may be used on the lower drawers to separate the rows of CDs within the drawer if they

are not filled to capacity. If the drawers are full, the CDs easily stay within their rows. A vertical cabinet then can be stacked on top of the lower cabinet, with drawers that can be viewed from the side with the spines of the CDs pointing toward the viewer. Dividers for the rows and a back-panel are necessary for the vertical drawers to keep the CDs from falling out. Lean is not an issue for CDs because they are stored in jewel cases placing no stress on the CDs themselves (see fig. 6 above).

CDs may also be stored in boxes and then placed on shelves. Acid-free boxes for CDs 6 ¼ x 5 ½ x 12 ¼ inches can hold 28 CDs in standard jewel cases. The boxes can be stacked two boxes high on shelving set with 13-14 inches between the shelves, the same as for 12-inch discs. A standard 3-foot shelf can hold twelve of these boxes. Stacking the boxes is not harmful to the CDs as the boxes are bearing all of the weight rather than the CDs themselves (fig. 24).



Figure 24 Compact Discs in a Box  
Stanford Archive of Recorded Sound

The CDs are easy to see and shift in cabinets, but the cabinets are not as space efficient as boxes on shelves given the extra aisle space needed to view the drawers when extended. Boxes on shelves can store more CDs per square foot than cabinets because extra aisle space needed especially if compact shelving is used. Two-foot deep cabinets require at least a four-foot aisle—two feet for the drawer when extended and another two feet for the viewer. Boxes on shelves have the advantage that a standard three-foot aisle may be used. Also, the compact disc collection can easily be moved at a later time, and the shelves can be reused for 12-inch discs.

## 6.3 Magnetic Media

### 6.3.1 Magnetic Tapes

#### 6.3.1.1 Reel-to-Reel Tapes

##### 6.3.1.1.1 Storage Recommendations

###### 6.3.1.1.1.1 Material type: 7 inch reels (1/4 inch tape)

Storage container: Original cardboard or plastic boxes containing tape on unslotted plastic or metal reels

Storage method: Metal cantilever or L & T type shelving, single or double-face units generally 3 feet wide, with shelves 3 feet by 9 inches (actual); shelves set for 9-10 inches between shelves

Shelving features: Dividers adjustable at one inch increments and placed every 6 inches when the shelf is filled to capacity (6 dividers per shelf); all shelving surfaces should be smooth with no hardware coming in contact with the discs; backstop for each shelf or a back panel for the shelving unit.

Total capacity: ca. 50 tapes per three-foot shelf

Load bearing capacity: at least 17 lbs. per linear foot or ca. 40 lbs. per three-foot shelf



#### 6.3.1.1.2 Material type: 10 ½-inch reels (1/4-inch tape)

Storage container: Original cardboard or plastic boxes with an unslotted center hub containing tape on metal reels

Storage method: Metal cantilever or L & T type shelving, single or double-face units generally 3 feet wide, with shelves 3 feet by 12 inches (actual); shelves set for 12 inches between shelves

Shelving features: Dividers adjustable at one inch increments and placed every 6 inches when the shelf is filled to capacity (6 dividers per shelf); all shelving surfaces should be smooth with no hardware coming in contact with the discs; backstop for each shelf or a back panel for the shelving unit.

Total capacity: ca. 40 tapes per three-foot shelf

Load bearing capacity: at least 30 lbs. per linear foot or 90 lbs. per three-foot shelf

#### 6.3.1.1.2 Physical Characteristics

Most magnetic tape consists of a cellulose acetate or Mylar base to which a coating of a binder material mixed with iron oxide particles is attached. The tape is wound around a metal or plastic tape reel with one end of the tape at the central hub and an open end that is attached to a second reel for playback. Tape reels containing hubs without slots should replace with reels with a slotted hub, as slotted hubs cause deformation of the tape pack, which can result in playback problems.



**Figure 25 Five-, Seven-Inch Tapes with Slotted Hubs, and Ten and One-Half-Inch Tape**  
Stanford Archive of Recorded Sound

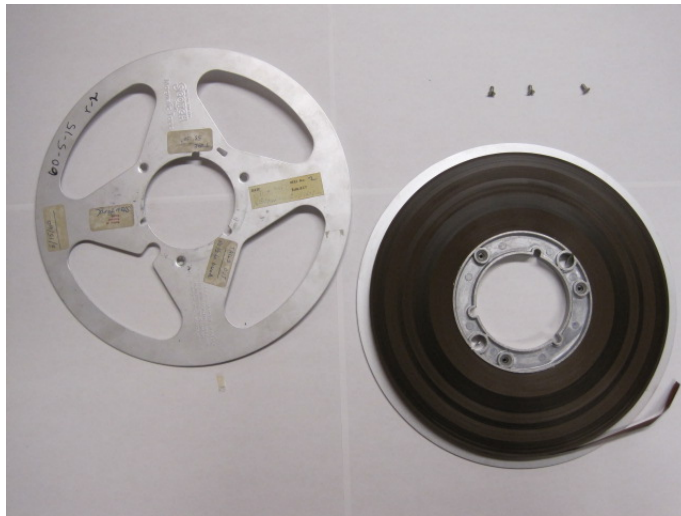
hub without a reel, and is sometimes known as a “pancake.” The tape was placed in a box where it was held in place by a central hub. To play the tape, re-useable metal flanges are attached to the central hub on each side of the pancake, which can then be placed on the tape machine. Pancakes should be handled with extreme care, because if the tape becomes loose

The most commonly found reel-to-reel tape size is ¼ inch wide, but professional recordings used tapes of ½, 1, 2, and even 3 inches wide. Plastic and metal tape reels are most commonly 7 or 10 ½ inches in diameter, although 3 and 5-inch reels are not uncommon (fig. 25-26). For professional recording, a 10-inch diameter tape was wound around a plastic



**Figure 26 Ten and One-Half-Inch Tape with Unslotted Hub**  
Stanford Archive of Recorded Sound

when not on a reel, it can take hours to rewind them by hand. Ideally, they should be wound on to metal reels for long-term storage, although this may be cost prohibitive in some situations. Fig. 27.

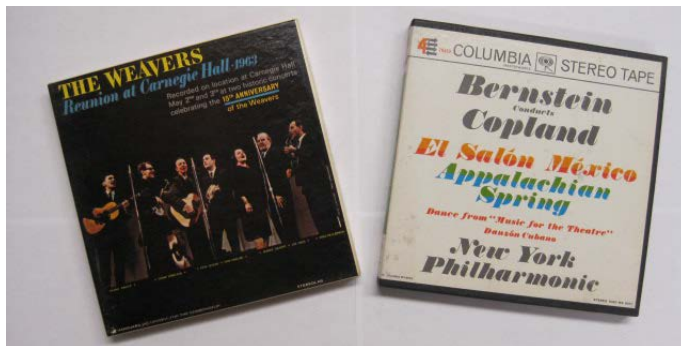


**Figure 27 Pancake Being Attached to Reel with Metal Flanges**  
Stanford Archive of Recorded Sound

The reels were distributed in cardboard or plastic boxes. Although the boxes are made of acidic paper, the tape itself is not in direct contact with the box if stored on a plastic or metal reel. Tape has been found to be an unstable material for the long-term storage of sound recordings. Its own physical properties will cause deterioration of the tape faster than the effect of storage in the original cardboard box under normal conditions. Therefore, it is not necessary to transfer the tape to an acid-free box in most archival situations.

#### 6.3.1.1.3 Shelf Arrangement

There were far fewer commercially produced pre-recorded reel-to-reel tapes than discs. However, those that were, used the same types of manufacturer numbers as discs and can be arranged by those numbers just as the discs are (fig. 28). The vast majority of reel-to-reel tapes are unique recordings and may be more easily maintained in an accession number or other order determined by the archive.



**Figure 28 Pre-Recorded Reel-to-Reel Tape**  
Stanford Archive of Recorded Sound

#### 6.3.1.1.4 Storage Details

Reel-to-reel tapes can be stored in their original boxes on standard shelving. Because the tape sizes correspond to the same standard sizes as disc materials (7 and 10 inches), the same shelving can be used for discs and tapes and can be set at the same heights. Tapes should be stored vertically rather than horizontally so that there is not unequal pressure from gravity on the reels that could cause warpage. It is important that the reels are perpendicular to the shelf and do not lean against one another or against the sides of the shelving. However, individual dividers are not as necessary for tapes as for discs, because the tape boxes stand up more easily and are not as heavy as discs (fig. 29). If the shelf is not full, a single divider or bookend at the end of the shelf is usually enough to keep all of the reels on the shelf upright. Even though it is a greater expense to use divided shelving, an archive may choose to use slotted shelving for its tape collection in case there is a need to re-use the shelving for discs at a later time. Standard library cantilever

shelving is suitable for reel-to-reel tapes because the weight of the tapes is much less than discs. Full-length dividers are not necessary because there is not the same concern with imprinting as there is with discs. The dividers need to provide enough support to keep the reels perpendicular to the shelf to avoid warping the reels.

There may be economies for using a different style and different sizes of shelving for tapes than for discs. However, in an archive that has large quantities of both tapes and discs, it is preferable to acquire shelving that accommodates the discs throughout the facility because tapes can also be stored on shelves intended for discs. For example, seven-inch reels can be stored on shelves that accommodate ten-inch shellac discs. However, the opposite is not possible. Ten-inch discs need slightly deeper shelves, full-length dividers, and a greater load-bearing capacity. Using shelving to meet higher requirements allows the archive greater flexibility for future collection needs.

Tape recordings can be affected by magnetic fields from circuitry and electronic equipment. Therefore, wooden shelving has been recommended for magnetic recordings.<sup>23</sup> However, in over fifty years, there have been no problems reported in the literature of tape collections affected by stray magnetic fields when stored on metal shelving. Under normal storage conditions there appears to be little risk of such damage occurring on metal shelving.



Figure 29 Reel-to-Reel Tape Storage  
NAVCC

### 6.3.1.2 Audiocassette Tapes

#### 6.3.1.2.1 Storage Recommendations

Material type: Audiocassette

Storage container: Plastic boxes (2 ¾ x 5/8 x 4 ¼ inches) containing the cassette, a shell enclosing tape on reels

Storage method: Metal cabinet with drawers

Drawer dimensions (interior): 4 x 32 5/16 x 15 1/2 inches, allowing 11 rows of cassettes, adjustable dividers optional; 4 x 32 5/16 x 15 1/2 inches, allowing 5 rows of cassettes

Capacity: based on cassettes in standard plastic cases, 253 cassettes per drawer

Load bearing capacity: 42 lbs. per drawer

Alternate storage method: Boxes (4 ¼ x 10 ¼ x 12 ¾ inches) containing 36 tapes each, stacked three high on metal cantilever or L & T type shelving, single or double-face units generally 3 feet wide, with shelves 3 feet by 14 inches (actual)

Shelving features: all shelving surfaces should be smooth with no hardware coming in contact with the discs; backstop for each shelf or a back panel for the shelving unit.

Total capacity: 9 boxes per three-foot shelf or ca. 325 tapes per three-foot shelf

Load bearing capacity: ca. 55 lbs. per three-foot shelf.

<sup>23</sup> Pickett and Lemcoe, 62.

#### 6.3.1.2.2 Physical Characteristics

Audio cassettes contain a 1/8 inch wide tape connected to two reels inside a protective plastic shell that is 2 1/2 x 1/2 x 4 inches. The cassettes were frequently packaged in plastic boxes 2 3/4 x 5/8 x 4 1/4 inches. The plastic boxes usually include a paper insert with information about the recording (fig. 30).

#### 6.3.1.2.3 Shelf Arrangement

Audiocassettes were produced in great quantities, and an archive with a large collection of cassettes may wish to arrange the cassettes by manufacturer number in cabinets to allow for shifting as cassettes are added to the collection. If the collection is accessioned, the cassettes can be efficiently stored in boxes placed on shelves.

#### 6.3.1.2.4 Storage Details

Audiocassettes may be stored in drawers and cabinets designed for their uniform size. Metal drawers are preferable to wood for durability and ease of operation. As with reel-to-reel tape there is little evidence of damage from stray magnetic fields to cassettes stored in metal shelving. Horizontal drawers can be used up to about four feet high. Above this height, it becomes difficult to see inside the drawers to retrieve the cassettes. The cassettes are placed with the spine up inside the drawers in rows for easy identification. Dividers may be used inside the drawers to keep the cassettes in rows. However, if the drawers are full, dividers are not necessary, as the cassettes do not move around, and therefore will not become disorganized. Cabinets containing vertical drawers may be placed above the cabinets with horizontal drawers and require slots to hold the cassettes in place. Vertical drawers should not go much higher than six feet as it becomes difficult to retrieve the cassettes. A backstop is necessary in the upper drawers to hold them in place. Storing cassettes in drawers provides the greatest ease of retrieval and is relatively space efficient. Aisles must be larger than with shelves as sufficient room is required to extend a drawer fully while allowing space for the user.

Boxes on shelves are an alternative to cabinets when the cassettes are accessioned, although not quite as easily accessible. The same shelving employed for books and discs can be used for cassettes in boxes with the



Figure 30 Audiocassette with Box  
Stanford Archive of Recorded Sound



Figure 31 Cassettes in Box  
Stanford Archive of Recorded Sound



same aisle spaces, and reduced aisle space may be possible if compact shelving is used. Acid-free boxes for cassettes 4 ¼ x 10 ¼ x 12 ¾ inches can hold two rows of 36 cassettes, or two linear feet (fig. 31). The boxes can be stacked three boxes high to fit into shelving set at heights for 12-inch discs. Stacking the boxes is not harmful to the tapes as the boxes are bearing all of the weight rather than the cassettes (fig. 32).

### 6.3.1.3 Digital Audio Tape (DAT)

#### 6.3.1.3.1 Storage Recommendations

Material type: DAT

Storage container: Plastic boxes (2 5/16 x 3 3/16 x 5/8 inches) containing the cassette, a shell enclosing tape on reels

Storage method: Metal cabinet with drawers

Drawer dimensions (interior): 4 x 32 5/16 x 15 1/2 inches, allowing 9 rows of DATs per drawer, 32 DATs per row, adjustable dividers optional

Capacity: ca. 285 DATs per drawer based on DATs in standard plastic cases.

Load bearing capacity: ca. 30 lbs. per drawer

Alternate storage method: Boxes containing 50 DATs each (4 ¼ x 10 ¼ x 12 ¾ inches) stacked three high on metal cantilever or L & T type shelving, single or double-face units generally 3 feet wide, with shelves 3 feet by 14 inches (actual)

Shelving features: all shelving surfaces should be smooth with no hardware coming in contact with the discs; backstop for each shelf or a back panel for the shelving unit.

Total capacity: 9 boxes per three-foot shelf or ca. 450 tapes per three-foot shelf

Load bearing capacity: ca. 45 lbs. per three-foot shelf

#### 6.3.1.3.2 Physical Characteristics

DATs contain a tape connected to two reels inside a protective plastic shell that is 2 1/8 x 2 7/8 x 3/8 inches. DATs were frequently packaged in plastic boxes 2 5/16 x 3 3/16 x 5/8 inches. The plastic boxes usually include a paper insert with information about the recording (fig. 33).

#### 6.3.1.3.3 Shelf Arrangement

DATs were produced primarily for professional recording and for use by sophisticated amateurs. Very few pre-



Figure 32 Cassettes in Boxes on Shelf  
Stanford Archive of Recorded Sound



Figure 33 Digital Audio Tape (DAT) with Box  
Stanford Archive of Recorded Sound

recorded DATs were produced. DATs are usually accessioned or arranged in collections.

#### 6.3.1.3.4 Storage Details

DATs are usually stored in the same cabinets or boxes as are used for cassettes and are stored with the spine facing up for easy identification. Dividers help to keep the rows separate. Because of their small size vertical drawers used for cassettes and CD storage are not used for DATs. Cabinets provide convenient access and have the same issues of increased aisle space as for cassette storage

Boxes on shelves are an alternative to cabinets when the DATs are accessioned. The same boxes used for cassettes, acid-free boxes 4 1/4 x 10 1/4 x 12 3/4 inches, may be used to hold 50

DATs. The boxes can be stacked three boxes high to fit into shelving set at heights for 12-inch discs. Stacking the boxes is not harmful to the DATs as the boxes are bearing all of the weight rather than the material itself (fig. 34).



Figure 34 DATs in Box  
Stanford Archive of Recorded Sound

#### 6.3.1.4 Tape Cartridges

##### 6.3.1.4.1 Storage Recommendations

Material type: Tape Cartridge (8-track tapes)

Storage container: Plastic cartridge shell (5 3/8 x 4 x 7/8 inches) containing the tape on reels

Storage method: Cantilever or metal L & T type shelving, single or double-face units generally 3 feet wide, with shelves 3 feet by 13 inches (actual); cartridges arranged in boxes 6 1/4 x 5 1/2 x 12 1/4 inches stacked 2 high per shelf

Shelving features: all shelving surfaces should be smooth with no hardware coming in contact with the items; backstop for each shelf or a back panel for the shelving unit.

Total capacity: 13 cartridges per box; 12 boxes per shelf; ca. 155 cartridges per three-foot shelf

Load bearing capacity: ca. 45 lbs. per three-foot shelf

Alternate storage method: Metal cabinet with drawers

Drawer dimensions (interior): 6 5/16 x 44 1/2 x 22 3/16 inches with adjustable dividers, allowing 9 rows of cartridges per drawer

Capacity: 215 cartridges per drawer

Load bearing capacity: ca. 62 lbs. per drawer



#### 6.3.1.4.2 Physical Characteristics

Audio tape cartridges, commonly known as 8-track tapes, contain a 1/4 inch wide tape loop connected to a reel inside a protective plastic shell that is 5 3/8 x 4 x 7/8 inches. The cartridges sometimes came in a protective thin cardboard box covering the cartridge and open on one end (fig. 35).

#### 6.3.1.4.3 Shelf Arrangement

Audio cartridges contained pre-recorded music and were common from about 1965 through the end of the 1970s. They frequently duplicate recordings also marketed on LPs and cassettes. With the advent of the compact disc, production of 8-track tapes largely ceased. The cartridges may be arranged by manufacturer number in cabinets to allow for shifting as they are added to the collection. If the collection is accessioned, they can be efficiently stored in boxes placed on shelves.

#### 6.3.1.4.4 Storage Details

Audio cartridges may be stored in drawers and cabinets used for CD storage, as they are almost the same height as a standard CD jewel case. See the description of CD cabinets in section 6.2.4.4. The cartridges are placed with the spine up inside the drawers in rows for easy identification. Dividers should be used inside the drawers to keep the cartridges in rows. Storing cartridges in drawers provides the greatest ease of retrieval and is relatively space efficient.

Boxes on shelves are an alternative to cabinets when the cartridges are accessioned, although less easily accessible. The same shelving as is used for discs can be used for cartridges in boxes with the same aisle spaces, and reduced aisle space may be possible if compact shelving is used. Cartridges may be stored in the same boxes used for CDs and then placed on shelves. Acid-free boxes for CDs 6 1/4 x 5 1/2 x 12 1/4 inches can hold 13 cartridges, and the boxes can be stacked two boxes high on shelving set for 12-14 inches between the shelves. A standard 3-foot shelf can hold twelve of these boxes. Stacking the boxes is not harmful to the cartridges as the boxes are bearing all of the weight rather than the cartridges themselves. Collections with large numbers of 8-track tapes may wish to order custom size boxes for greater space efficiency as the cartridges are an inch narrower than CDs, which will allow for two more boxes per shelf than using CD boxes.



Figure 35 Tape Cartridges (8-Track Tapes)  
Stanford Archive of Recorded Sound

## 6.3.2 Magnetic Wires

### 6.3.2.1 Storage Recommendations

Material type: Wire (Webster)

Storage method: Metal cabinet with drawers

Drawer dimensions (interior): 4 x 32 5/16 x 15 1/2 inches, allowing 11 rows of wires per drawer, adjustable dividers optional

Capacity: based on wires in standard paper boxes. 286 wires per drawer

Load bearing capacity: ca. 125 lbs. per drawer

Alternate storage method: Boxes (4 1/4 x 10 1/4 x 12 3/4 inches), holding 44 wires 3 boxes per shelf on cantilever or L & T type shelving, single or double-face units generally 3 feet wide, with shelves 3 feet by 14 inches (actual)

Shelving features: all shelving surfaces should be smooth with no hardware coming in contact with the items; backstop for each shelf or a back panel for the shelving unit.

Total capacity: 3 boxes per shelf or ca. 130 wires per three-foot shelf

Load bearing capacity: ca. 60 lbs. per three-foot shelf

### 6.3.2.2 Physical Characteristics

Recorded wires come in a variety of sizes and adaptations to these recommendations may be needed to account for these differences. They were in wide-spread use from about 1945-55. Wires of the Webster-Chicago Co. are described here and the principles may be applied to other wires of different dimensions. The steel wire is extremely fine, about the thickness of human hair or very thin fishing line, and is wrapped around a metal spool 5/8 inches thick x 2 3/4 inches in diameter with a large center hole. The wire recorder is similar to a tape recorder, in that the wire moves from one spool across a record/playback head and is deposited on a take-up spool. The wires were frequently packaged in paper boxes 3 x 3/4 x 3 inches (fig. 36).



Figure 36 Pierce, Leer, and Webster Wire Recordings  
Stanford Archive of Recorded Sound

### 6.3.2.3 Shelf Arrangement

Wires were used for instantaneous recordings such as dictation and recording radio broadcasts. They were not used for distributing mass produced pre-recorded music. Consequently, they can be accessioned or grouped in collections.

#### 6.3.2.4 Storage Details

Wires may be stored in drawers and cabinets used for cassettes. Horizontal drawers can be used up to about five drawers high. Dividers may be used inside the drawers to keep the wires in rows. However, if the drawers are full, dividers are not necessary, as the wires do not move around. Aisles must be larger than with shelves as there needs to be room to extend the drawer fully and room in the aisle for the user. Floor loading capacity for large collections of wires is a serious consideration. As with lacquer discs, the cabinets should be loaded starting with the bottom drawer, because the cabinet could become top heavy and tip over with wires only in the top few drawers.

The boxes used for cassettes (4 ¼ x 10 ¼ x 12 ¾ inches) may also be used and will hold up to 44 wires in four rows of eleven each (fig. 37). A single box filled to capacity can weigh up to 19 ¼ lbs. The same shelving as is used for twelve-inch discs can be used for wires in boxes. Acid-free boxes for cassettes 4 ¼ x 10 ¼ x 12 ¾ inches can hold two rows of 36 cassettes, or 2.75 linear feet. Stacking the boxes as with cassettes is not recommended. Since the boxes weigh nearly 20 lbs. each, the center of the boxes will bow under the weight and place stress on the box below. When using boxes for wires, they should be placed directly on the shelf so that the full weight of the box is fully supported. Boxes filled with cassettes or lighter materials may be placed on top of boxes filled with wires to make more efficient use of the space between shelves.



Figure 37 Wire Recordings in a Box  
Stanford Archive of Recorded Sound

## 7 Conclusions

Shelving for audio recording collections has many complexities. The recommendations above may need to be adapted to local practices and conditions. Fitting shelving and cabinets into an existing building may also require variation from these recommendations. However, the general principles can still be applied when working with a shelving supplier and installer.

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<b>Appendix</b>				
<b>Recording Types: Size and Weight</b>				
Format	Size in inches (diameter or h x w x d)	Container size in inches (h x w x d)	Items/lin.ft.	Lbs./lin.ft.
Cylinder	4 1/4 x 2 1/8	5 x 2 9/16	5.5	0.75
(dictation)	6 1/8 x 2 5/16	6 3/4 x 2 3/4	4	2
(Grand Concert)	4 7/8 x 4 1/4	6 1/4 x 4 3/4	2.4	2.5
Shellac Disc (78 rpm)	7		120	20
	10		110	52
	12		98	74
Edison disc	10		48	48
Vinyl Disc	7		122	12
*	10		74	37
	12		87	48
(box set)	12		56	34
Lacquer disc	10		53	57
	12		160	82
	16		136	168
CD	4 3/4	4 7/8 x 5 9/16 x 3/8	30	8
(double case)		4 7/8 x 5 9/16 x 15/16	13	6
Reel tape	7 x 1/2	7 1/8 x 5/8 x 7 1/8	17	14
	10 1/2 x 1/2	10 7/8 x 7/8 x 10 7/8	13	29
Tape cassette	2 1/2 x 1/2 x 4	2 3/4 x 5/8 x 4 1/4	18	3
Tape cartridge	5 3/8 x 4 x 7/8		14	4
Wire (Webster)	5/8 x 2 3/4	3 x 3/4 x 3	16	7
DAT	2 1/8 x 2 7/8 x 3/8	2 5/16 x 3 3/16 x 5/8	19	2
<p>* The amount of space needed for 10-inch vinyl discs was greater than that for 12-inch discs. One would expect them to be about the same. The difference here may have been caused because the 10-inch discs tended to be older, being thicker with thicker cardboard jackets.</p>				